Bacteria Modeling Report for the East Fork San Jacinto River watershed

September 2022

This document was prepared by the Houston-Galveston Area Council (H-GAC) for the stakeholders of the East Fork San Jacinto watershed Partnership. It was prepared in cooperation with the Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (EPA).

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EAST FORK SAN JACINTO RIVER WATERSHED PARTNERSHIP

Houston-Galveston Area Council

United States Environmental Protection Agency

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SECTION 1: INTRODUCTION

The watershed area of the East Fork of the San Jacinto River includes portions of Harris, Montgomery, Liberty, San Jacinto, and Walker counties. Over 410 square miles of land are drained by a network of tributaries into the main stem of the East Fork of the San Jacinto River before ultimately discharging into Lake Houston (**Figure 1**). Land cover in the watershed varies and is characterized by heavily wooded areas, especially in the portions of the watershed spanning Walker and San Jacinto counties, which are part of the Sam Houston National Forest. Pasture and woody wetlands are also common in these areas. The southern part of the watershed is more developed, especially in Liberty and Harris counties. Development is expected to expand as growing populations push north from the Houston area along the US Highway 59 and State Highway 99 (Grand Parkway) transportation corridors. Small cities such as Cleveland, North Cleveland, Plum Grove, and Roman Forest intersect or are completely contained within the watershed area. Large cities intersecting the watershed area include Huntsville and Houston.

The most recent version of the Integrated Report of Surface Water Quality[1] produced by the Texas Commission on Environmental Quality (TCEQ) indicated exceedances of state water quality standards in many of the streams in the East Fork San Jacinto River watershed[2]. Specifically, high concentrations of the fecal indicator bacteria *Escherichia coli* (*E. coli*) resulting in impairments to contact recreation use were observed. Because *E. coli* are found in the digestive systems of people and animals, detecting high concentrations of this organism in the surface water indicates potential contamination from sources such as untreated sewage, agricultural runoff, or deposits from wild animals. Especially in cases where human waste pressures are indicated, there is also a likelihood that additional pathogens could be present in waterways. Without taking action to manage sources of contamination, recreation activities such as swimming and wading in streams will not be safe for communities of the watershed. More importantly, these negative effects could extend to the reservoir that East Fork San Jacinto River and its tributaries drain into, Lake Houston, which serves as a drinking water source for communities throughout the region.

To address these challenges, a watershed protection plan (WPP) will be developed which will outline the specific goals and action strategies set forth by local stakeholders to achieve water quality improvements. In their roles as facilitators to this stakeholder group, the Houston-Galveston Area Council (H-GAC) conducted a series of modeling efforts to provide stakeholders with a more comprehensive understanding of fecal bacteria sources impacting the East Fork San Jacinto River watershed. These modeling efforts include estimations for fecal bacteria load reductions needed to comply with state water quality standards determined with load duration curve (LDC) analyses. Additionally, potential fecal bacteria source load assessments for each of the subwatersheds in the project area were conducted using the Spatially Explicit Load Enrichment Calculation Tool (SELECT). These assessments will help to determine where and how improvements can be made to reduce negative impacts to water quality.

[1] This report references the 2022 version of the Texas Integrated Report of Surface Water Quality. These assessments determine which streams are classified as having impairments (measurements exceeding numerical or other specific state water quality standards) or concerns (exceedances of screening levels or other non-numeric/specific criteria).
[2] A more detailed analysis of water quality is discussed further in the Acquired Data Analysis Report for the East Fork San Jacinto Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the East Fork San Jacinto River Modeling Quality Assurance Project Plan) are available for review at https://eastforkpartnership.weebly.com/documents.html.

The following sections of this document will discuss:

- Needs of the project that will be met through modeling analyses.
- Types of models used in this report and how they fit into the design of the overall analysis.
- Results of LDC evaluations.
- Results of SELECT model evaluations.
- An overview of the outcomes and implications of the findings from this report.

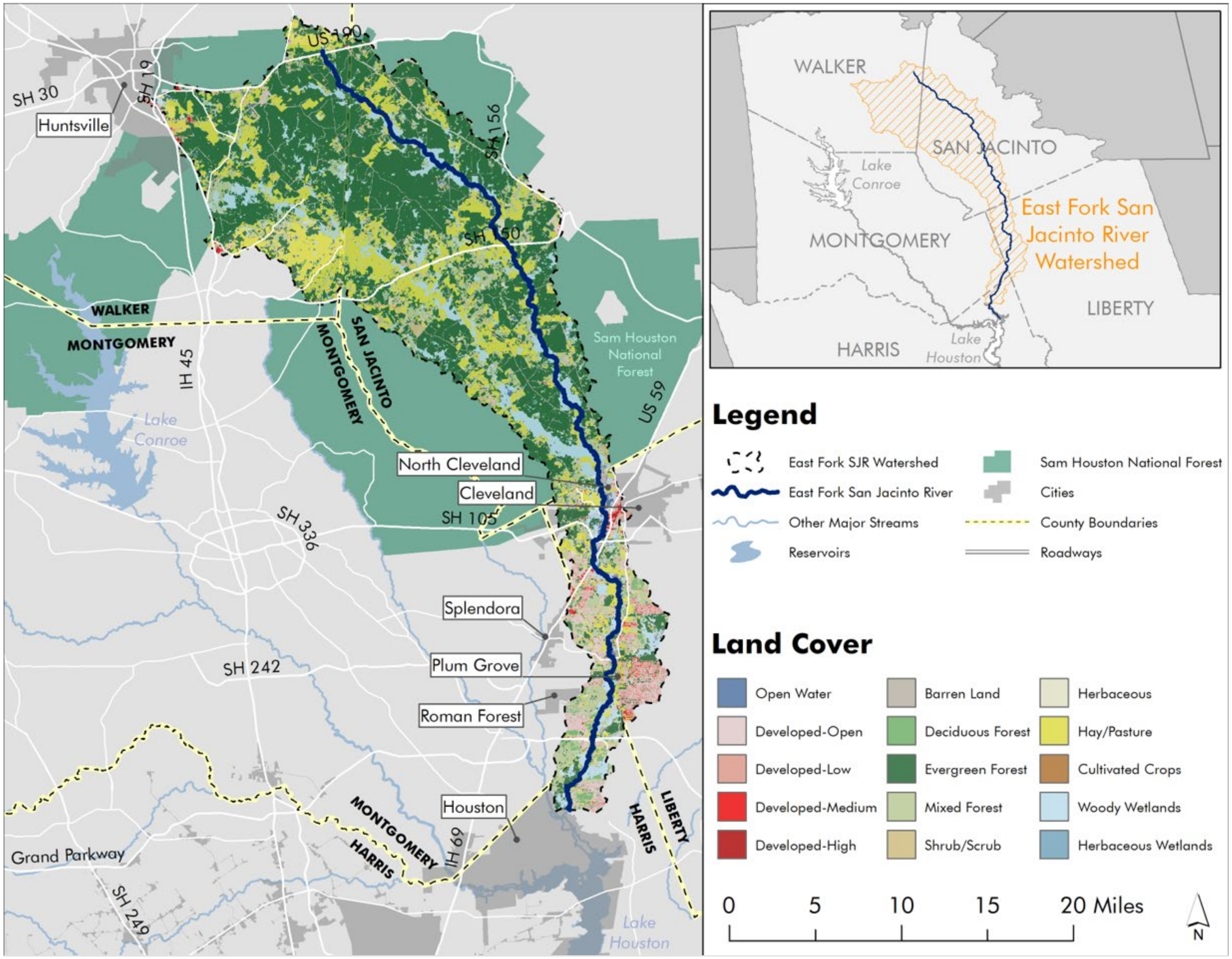

Figure 1. The East Fork San Jacinto River watershed, Land Cover, and Regional Context

Section 2: Project Needs

Model results are an important resource for stakeholders seeking to make watershed planning decisions. By observing modeled data, stakeholders will develop a better understanding of what pollutant sources are impacting the watershed, at what magnitudes pollutants are delivered to the system, where pollutant pressures are spatially distributed, and how to address these concerns most effectively. Beyond this primary need, the combination of modeling results, other data analyses, and stakeholder input is essential to the fulfillment of Element A of the United States Environmental Protection Agency (EPA) 9-element model for watershed-based plans[3].

Needs specific to the development of a WPP for the East Fork of the San Jacinto River include:

- Relating streamflow to pollutant loads to identify at which flow conditions exceedances of water quality standards are observed using LDC models.
- Establishing goals (fecal bacteria load reduction improvement benchmarks) necessary for compliance with state water quality standards using LDC models.
- Using fecal indicator bacteria data as proxy for estimating spatial relationships and source analysis of fecal waste loading in area subwatersheds using SELECT models.
- Using the LDC and SELECT model results to relate load reductions to source load data and estimate specific source load reductions.

As an additional consideration, both current and future source loading conditions will be assessed to account for the expansion of developed area and other land changes forecasted to take place in the watershed in the next 25 years.

Section 3: Model Selection and Analysis Design

3.1 Model Selection

To best suit the project needs described in Section 2, H-GAC staff selected LDC and SELECT models to represent pollutant loading data in the East Fork San Jacinto River watershed. These models strike the balance between efficiency and complexity and have been used widely on other WPP projects throughout the region.

After discussions between H-GAC and TCEQ regarding this project as well as similar watershed planning efforts, relating LDC reduction percentages linearly to SELECT source load estimation models was determined to be appropriate for decision-making needs related to WPP development. Fate and transport of pollutants are not captured by these models between source loads and could be more precisely represented by complex modes such as SWAT. However, the level of detail rendered from these intensive analyses ultimately does not provide more meaningful support for stakeholder decision-making and requires additional cost and time to develop. As part of the WPP, long-term monitoring and assessments of efficacy will be carried out which will help to offset the need for complex, predictive modeling.

Additionally, H-GAC staff incorporated modifications to the standard SELECT modeling process to counteract spatial generalization of results. By utilizing buffers—zones within a set distance of another feature—models can assign more weight to certain sets of results based on spatial relationships. In the case of watershed planning, potential pollutant loads from sources within buffers immediately surrounding

[3] As referenced at https://www.epa.gov/nps/handbook-developing-watershed-plans-restore-and-protect-our-waters

waterways can be given more weight than sources distributed outside the buffer according to higher likelihood of impact. Another modification to the SELECT models used in this report involved the utilization of a base assumption for wildlife impacts throughout the watershed. This helps to bridge the gap that the SELECT model can sometimes face when limited by sparse or insufficient wildlife data.

3.2 Analysis Design

According to findings from the most recent version of the Integrated Report of Surface Water Quality produced by TCEQ, the most widespread and frequently occurring impairment in the East Fork San Jacinto River watershed is caused by high levels of the bacteria *E. coli*, which can indicate the presence of fecal waste and pathogens in surface water. Water quality and spatial data used in this report were collected from quality assured sources including the Surface Water Quality Monitoring Information System and the National Hydrography Dataset. Using LDCs and SELECT models, the following analyses were designed to consider:

- Whether adequate water quality and flow data exist for the study area.
- Which of the major flow categories are of the highest concern in this watershed.
- Which locations throughout the watershed could act as benchmarks for monitoring progress toward water quality goals.
- What pollutant sources need to be incorporated into the models and where to acquire data to represent these sources.
- How to determine the best source estimations.
- At which points in the future to forecast projected loading values and how to develop them.
- How to incorporate the buffer method into a modified SELECT output.
- How stakeholder input could be used to refine these assessments.

Model results from LDCs and SELECT evaluations were combined to link reduction goals to specific source loads and develop effective water quality improvement strategies for the WPP. Future reduction targets derived from this assessment represent 5-year benchmarks through the year 2050.

SECTION 4: LDC EVALUATIONS

4.1 Overview

LDCs were used to characterize the relationship between pollutant loads and stream flow. By determining the difference between modeled loads and the maximum loads permitted by state water quality standards, reduction targets can be estimated.

4.2 Load Estimation

Origins of fecal waste indicated by *E. coli* in waterways are informed by the stream flow conditions observed at the time of sample collection. This information is also helpful in determining the strategies that will be most effective in reducing contamination. For example, if fecal bacteria levels are highest in periods of high flows seen during flooding events, then stormwater flows and other nonpoint sources are likely to be the major contributors to impairment. If fecal bacteria levels are highest when flows are limited, then point sources or sources known to steadily contribute contaminants into waterways are indicated as the greater concern.

To calculate LDCs for the East Fork of the San Jacinto River and its tributaries, stream flow data from the United States Geological Survey (USGS) and Clean Rivers Program (CRP) water quality data from the Surface Water Quality Monitoring Information System were used. USGS gage data is ideal to produce flow duration curves used in LDC analyses due to the long-term, continuous measurements recorded by the gages. Based on the percentage of days during the study period in which flows of a known magnitude are observed, a flow duration curve is developed and plotted. Additional curves resulting from the multiplication of state water quality standards and values of the flow duration curve are added to the plot to represent the maximum allowable contaminant loads during each flow condition. Finally, individual observed pollutant levels collected during the study period and a curve modeled from these observations (load regression curve) are plotted. For areas where the load regression curve exceeds the maximum allowable contaminant load curve, reductions are needed.

4.3 Site Selection

Locations of monitoring data used for LDC analyses were selected based on their periods of record, water quality conditions, availability of corresponding stream flow data, and representativeness of smaller drainage areas within the greater watershed known as subwatersheds. Subwatershed delineation is useful as a means of yielding more spatially specific information that can be used to target source load reductions with greater precision. This analysis references the six subwatersheds (**Figure 2**) described below.

1) **Lower East Fork San Jacinto River (SW1)** – the drainage area of Assessment Unit (AU) 1003_01, which is made up of the lower third of the East Fork San Jacinto River. Land cover in this subwatershed is more developed compared to the others. This waterbody begins due south of Cleveland, TX and forms a confluence with Lake Houston. This area is represented by Station 11235 (East Fork San Jacinto River at FM 1485) and stream flow was assessed from USGS gage 08070200.
2) **Middle East Fork San Jacinto River (SW2)** – the drainage area of AU 1003_02, which is made up of the middle third of the East Fork San Jacinto River. This area is represented by USGS gage 08070000 was used to measure flow at Station 11238.
3) **Upper East Fork San Jacinto River (SW3)** – the drainage area of AU 1003_03, which is made up of the upper third of the East Fork San Jacinto River. This area is represented by Station 17431 (East Fork San Jacinto River at SH 150). This station is not represented by a USGS gage, but because it occurs on the same water body as a gaged station (11238), stream flow was estimated by applying a drainage area ratio. To do this, the drainage area of 11238 was compared to that of 17431 to determine a ratio to use as a multiplier for daily mean stream gage measurements taken at 11238. The resulting values were used as daily flow values for 17431.
4) **Winters Bayou (SW4)** – the drainage area of AU 1003A_01, which is made up of the full length of Winters Bayou. Though this area is characterized by mostly natural land cover types, it is also the subwatershed with the highest concentration of agricultural land cover. Ambient data for this area are represented by Station 21417 (Winters Bayou at Tony Tap Road near Cleveland) Station 21417 occurs after the confluence with Nebletts Creek but before the confluence with the East Fork San Jacinto River. This station is not represented by a USGS gage. Because 21417 occurs on a separate water body from the nearest USGS gaged station (11238), a linear regression method was applied. Instantaneous flows measured during quarterly sampling events at 21417 were compared to daily mean flow measured at 11238 to develop a linear regression equation. This equation was applied to daily mean flows from 11238 to estimate daily flows at 21417.

5) **Nebletts Creek (SW5)** – the drainage area of Nebletts Creek (AU 1003B_01), a tributary to Winters Bayou. This area is covered mostly by natural land types, especially forest. Though there is a monitoring station on Nebletts Creek, there is no stream gage. Further, Nebletts Creek was not listed for any concerns or impairments in the *2022 Texas Integrated Report of Surface Water Quality*. For these reasons, no LDC analysis was performed for this subwatershed.
6) **Boswell Creek (SW6)** – the drainage area of Boswell Creek (AU 1003C_01), a tributary to Winters Bayou. Ambient data were collected from Station 21934 (Boswell Creek at Four Notch Road). As with Station 17431 in SW3, stream flow data were assessed by applying a drainage area ratio to the regression values from 21417. The drainage area ratio was used in this case as opposed to the regression method due to the limited record of instantaneous flow data available at this station.

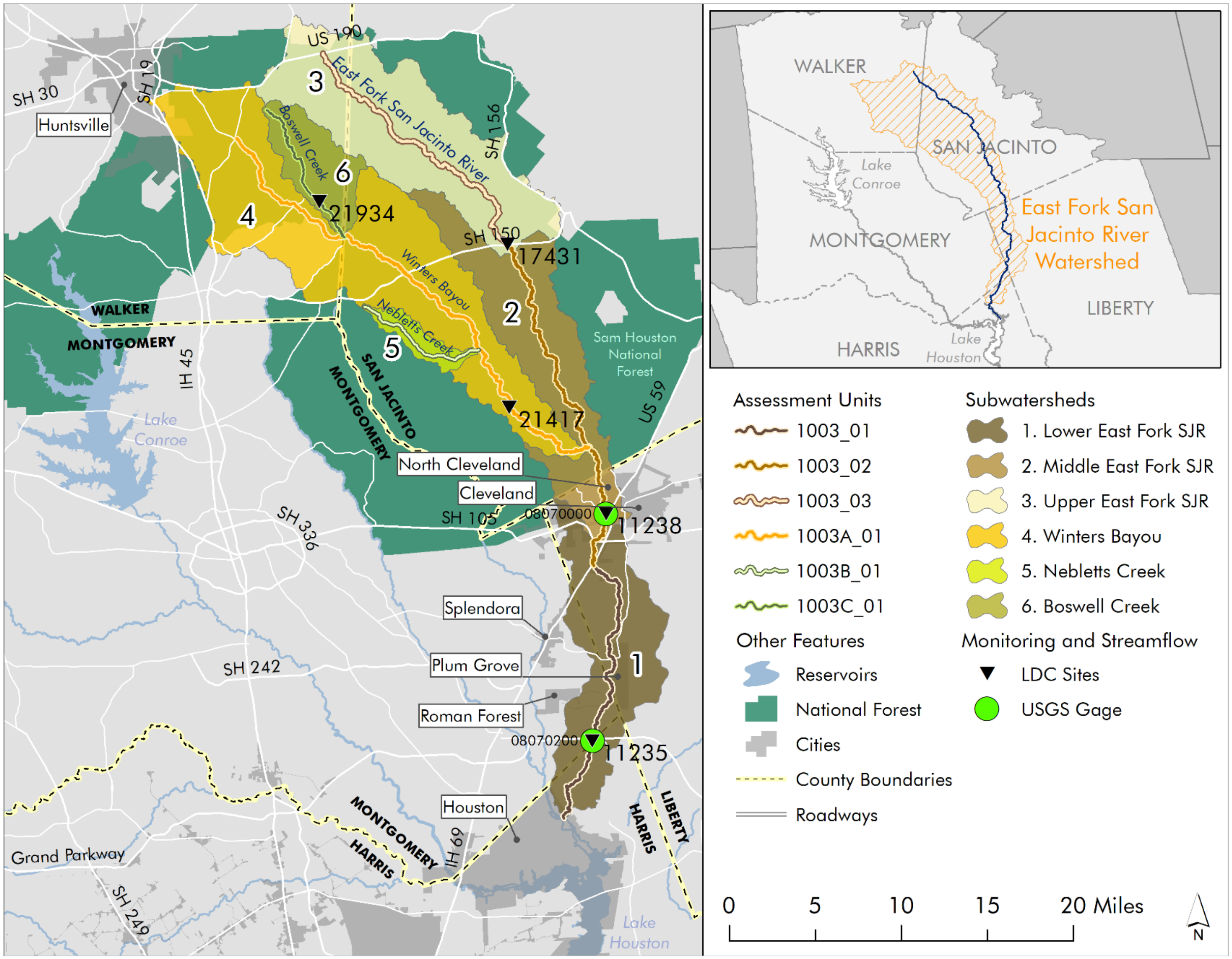

Figure 2. Subwatersheds of the East Fork San Jacinto River watershed

Ambient water quality data are collected at over 400 sites in the 13-county Houston-Galveston region by H-GAC, local partners, and TCEQ as part of CRP. In general, most monitoring stations are sampled by CRP partners on a quarterly frequency for a suite of field, bacteriological, and conventional parameters. The final determination of the regulatory status of each segment is based primarily on these ambient data. The impetus for development of the WPP was formed largely in response to the current regulatory status of the East Fork of the San Jacinto River and its tributaries, therefore ambient data is a relevant source of information for informing stakeholder decisions. Ambient data used for LDC analyses were collected in the East Fork San Jacinto River watershed between 2012 and 2021 at five locations (**Figure 2**; **Table 1**).

Table 1. LDC Locations

LDC Site	CRP Station	USGS Gage	Assessed Area
East Fork San Jacinto River at FM 1485	11235	08070200	Subwatershed 1
East Fork San Jacinto River at SH 105	11238	08070000	Subwatershed 2
East Fork San Jacinto River at SH 150	17431	No Gage	Subwatershed 3
Winters Bayou at Tony Tap Road near Cleveland	21417	No Gage	Subwatershed 4
Boswell Creek at Four Notch Road	21934	No Gage	Subwatershed 6

4.4 Data Development

In addition to location and availability of stream flow data, sufficiency and consistency of ambient data collection were important factors leading to the selection of the six CRP stations used for LDC analysis. The number of quality assured data values for *E. coli* are expressed in **Table 2**. All stations on the East Fork of the San Jacinto River have at least 10 years of data available and range from 33 to 59 samples for *E. coli*. Regular sampling on the tributaries to the East Fork of the San Jacinto River, Winters Bayou and Boswell Creek, have begun in more recent years, therefore, the dataset is more limited. However, an analysis of these waterbodies will provide a more complete understanding of bacteria loading throughout the watershed.

Table 2. Number of Samples by Station

LDC Location	Station	# of *E. coli* Samples
East Fork San Jacinto River at FM 1485	11235	59
East Fork San Jacinto River at SH 105	11238	58
East Fork San Jacinto River at SH 150	17431	33
Winters Bayou at Tony Tap Road near Cleveland	21417	31
Boswell Creek at Four Notch Road	21934	17

4.5 LDC Implementation

Project staff used the data referenced above to generate flow curves and LDCs. While both geomean and single sample data for fecal bacteria were assessed, at each station observed in this report, only the geomean results were used for determining reduction targets. Values labeled “Geometric Mean Load” (gray squares) represent the geometric mean of the modeled bacteria load values within a specific flow condition. The distance between this point and the standard curve represents the reduction needed (represented as percentages on corresponding table). Negative values indicate that no reductions or improvements are needed in associated stream flow conditions. No appreciable issues were identified in LDC development based on quality assured internal review, however results of these analyses will be discussed in greater detail with project stakeholders to verify accuracy and representativeness.

Station 11235 – East Fork San Jacinto River at FM 1485

Station 11235 is located on AU 1003_01, the southernmost section of the East Fork San Jacinto River. The subwatershed for this station is comprised of the most diverse land cover types of all the areas observed in this analysis. As with all other subwatersheds, the majority (41%) is forested. However, 32% is developed, making it the most developed subwatershed in this analysis. Other notable land types include 14% wetland areas and 10% agricultural land. The majority (99%) of daily average rates of stream flow in cubic feet per second (cfs) on AU 1003_01 are estimated to be between 0 and 5,000 cfs. The highest 1% of flows ranged from 5,000 to 100,000 cfs with the highest recorded value occurring during the peak of Hurricane Harvey in 2017. Also of note, the period of record included data points from the final months of a statewide drought which occurred between late 2010 and 2012.

The results of LDC analyses for Station 11235 (**Figure 3**; **Table 3**) indicate a need for moderate reductions in fecal bacteria loading at high flow, moist, mid-range, and dry conditions. *E. coli* geomean loads expressed in billion colony forming units per day (cfu/day) were higher at higher levels of flow and implicate nonpoint sources as the greater pressure in this subwatershed area.

Table 3. Flow Specific Values for LDC 11235

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample
High Flows	0-10%	83%	47%
Moist Conditions	10-40%	56%	-38%
Mid-Range Conditions	40-60%	31%	-118%
Dry Conditions	60-90%	1%	-212%
Low Flows	90-100%	-1029%	-3475%

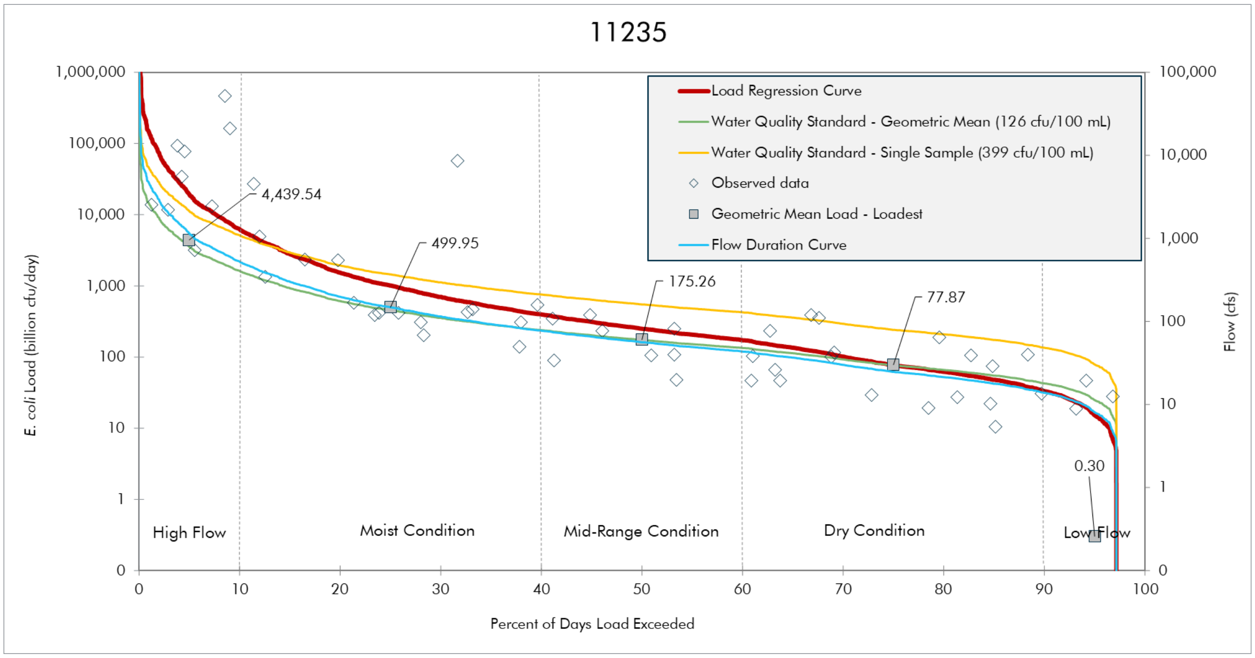

Figure 3. *E. coli* LDC for Station 11235

Station 11238 – East Fork San Jacinto River at SH 105

Station 11238 is located on AU 1003_02, the middle portion of the East Fork of the San Jacinto River. Forested areas make up 57% of the land cover in the drainage area for this waterbody. Other notable land cover types include 16% agricultural land, 15% wetlands and 9% developed areas. Flow variability at this station is similar to that of 11235 with 99% of flows ranging from 0 to 4,000 cfs and the top 1% ranging from 4,000 to 90,000 cfs. As with 11235, the highest flows were observed during the flooding associated with Hurricane Harvey in 2017.

The results of LDC analyses for Station 11238 (**Figure 4**; **Table 4**) indicate that fecal bacteria require reduction in high flows, moist, and mid-range conditions. Comparative to Station 11235, reduction levels at Station 11238 were comparable in high flow and moist conditions. *E. coli* geomean loads at mid-range were lower than at 11235 and were within state standard range in both dry and low flow conditions.

Table 4. Flow Specific Values for LDC 11238

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample
High Flows	0-10%	86%	57%
Moist Conditions	10-40%	45%	-73%
Mid-Range Conditions	40-60%	4%	-204%
Dry Conditions	60-90%	-56%	-393%
Low Flows	90-100%	-170%	-754%

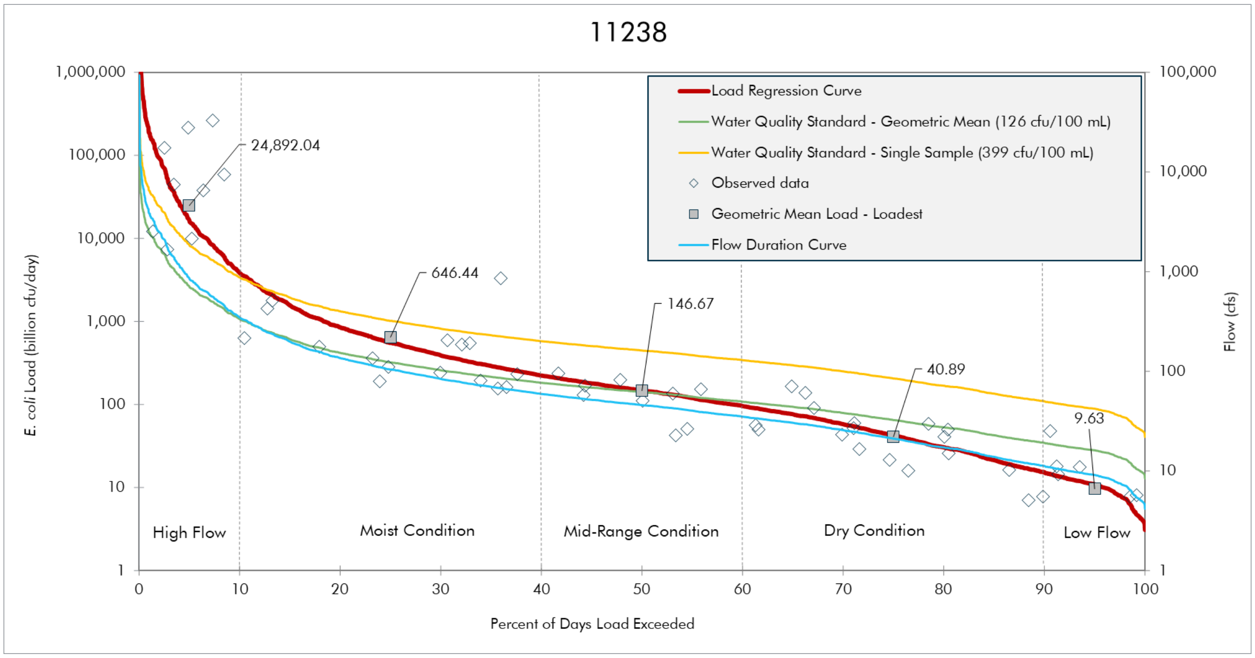

Figure 4. *E. coli* LDC for Station 11238

Station 17431 – East Fork San Jacinto River at SH 150

Station 17431 is located on the upper portion of the East Fork of the San Jacinto River (AU 1003_03). Forested areas make up 65% of the land cover in the drainage area for this waterbody. Other notable land cover types include 16% agricultural land, 10% wetlands and 6% developed areas. Stream flow is lower on this portion of the river compared to Stations 11238 and 11235. Most flows ranged from 0 to 1,000 cfs with exceptional flows associated with flooding events ranging between 1,000 and 26,000 cfs.

The results of LDC analyses for Station 17431(**Figure 5**; **Table 5**) are more in line with the analysis conducted on 11235 in that reductions in fecal bacteria are recommended for all flow conditions excluding low flow.

Table 5. Flow Specific Values for LDC 17431

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample
High Flows	0-10%	95%	85%
Moist Conditions	10-40%	73%	16%
Mid-Range Conditions	40-60%	47%	-67%
Dry Conditions	60-90%	4%	-203%
Low Flows	90-100%	-87%	-492%

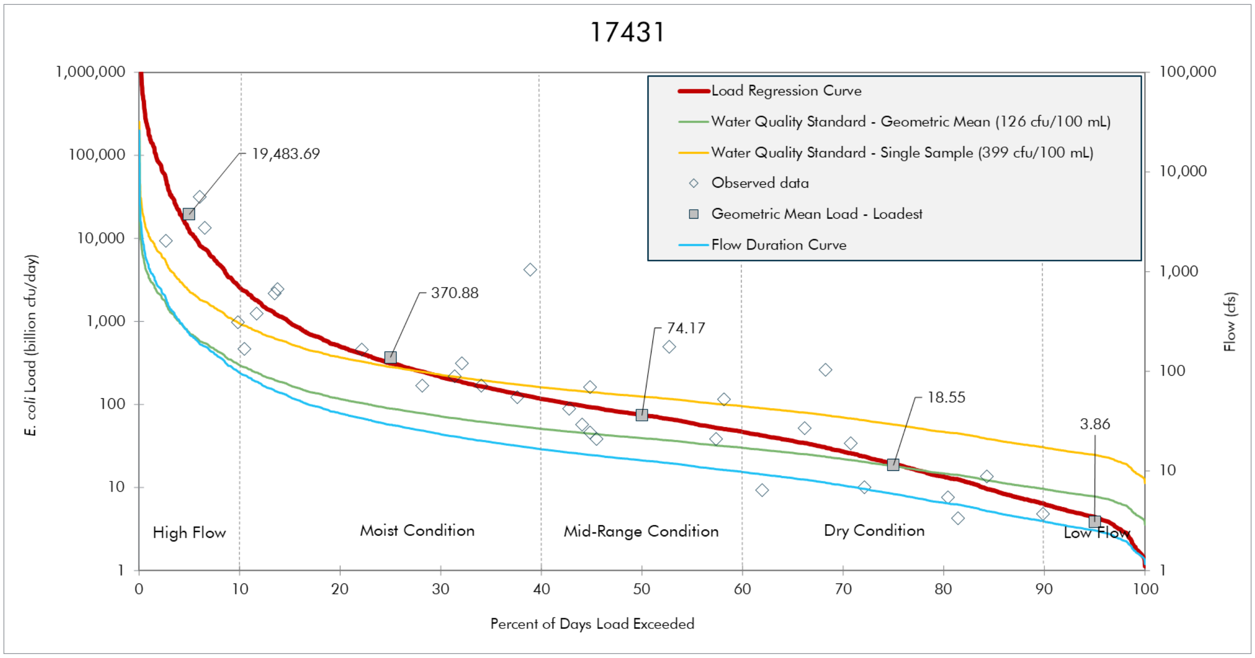

Figure 5. *E. coli* LDC for Station 17431

Station 21417 – Winters Bayou at Tony Tap Road near Cleveland

Station 21417 occurs on Winters Bayou (AU 1003A_01), a tributary to the East Fork of the San Jacinto River which joins the river from the west at a point just north of Station 11238. Forested areas make up 52% of the land cover in the drainage area for this waterbody. This subwatershed also has the highest percentage (29%) of agricultural land relative to the other subwatersheds in this analysis. Other notable land cover types include 10% wetlands and 7% developed areas. Most flows ranged from 0 to 2,000 cfs with exceptional flows associated with flooding events ranging between 2,000 and 42,000 cfs.

The results of LDC analyses for Station 21417 (**Figure 6**; **Table 6**) differ from those observed in the East Fork of the San Jacinto River in that *E. coli* reductions are only required in high flow and moist conditions. This indicates that nonpoint sources of fecal bacteria loading are of greater concern at this site.

Table 6. Flow Specific Values for LDC 21417

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample
High Flows	0-10%	70%	6%
Moist Conditions	10-40%	25%	-136%
Mid-Range Conditions	40-60%	-10%	-248%
Dry Conditions	60-90%	-58%	-400%
Low Flows	90-100%	-159%	-719%

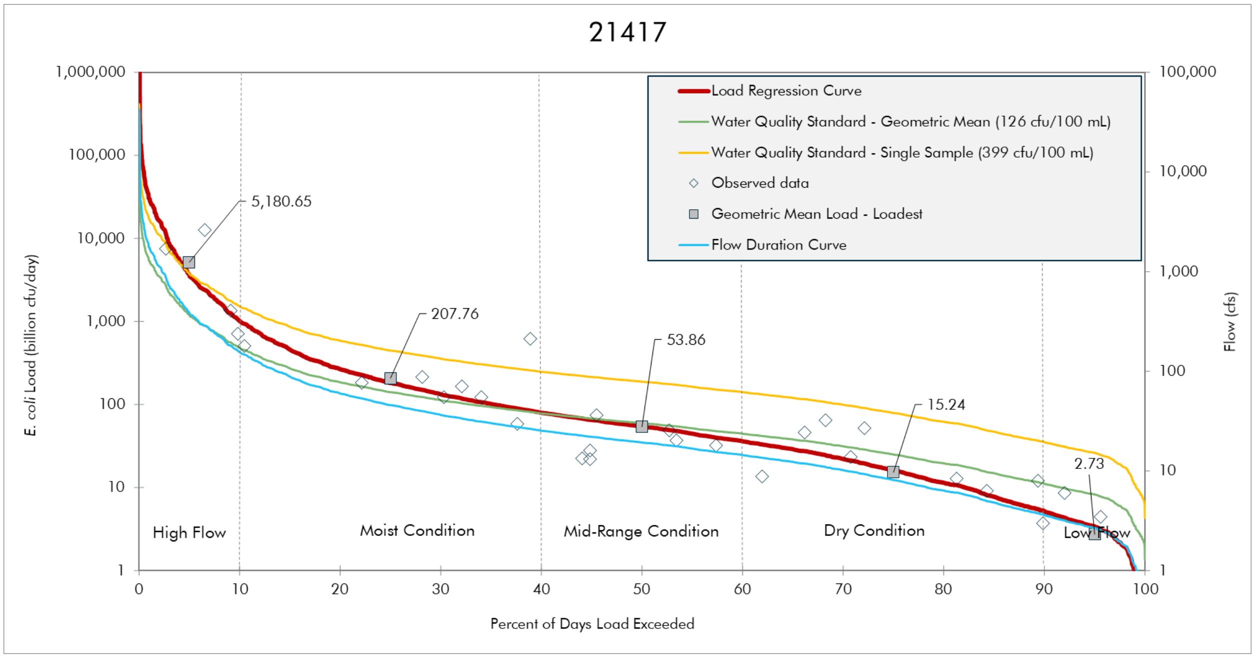

Figure 6. *E. coli* LDC for Station 21417

Station 21934 – Boswell Creek at Four Notch Road

Station 21934 occurs on Boswell Creek (AU 1003C_01), a tributary to Winters Bayou, which itself is a tributary to the East Fork of the San Jacinto River. The drainage area for this waterbody is the most heavily forested of all subwatersheds observed in this study with a total of 80% forest. The remaining land cover types include 9% wetlands, 7% agricultural land, and only 3% developed areas. The lowest rates of flow of all the stations observed in this report occurred at this location. Most flows ranged from 0 to 2000 cfs with exceptional flows associated with flooding events ranging between 200 and 4,000 cfs.

The results of LDC analyses for Station 21934 (**Figure 6**; **Table 6**) more closely resembled those of Station 21417 with exceedances of the *E. coli* water quality standard observed only in periods of high flow and in moist conditions.

Table 7. Flow Specific Values for LDC 21934

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample
High Flows	0-10%	95%	85%
Moist Conditions	10-40%	57%	-37%
Mid-Range Conditions	40-60%	-11%	-253%
Dry Conditions	60-90%	-169%	-752%
Low Flows	90-100%	-795%	-2735%

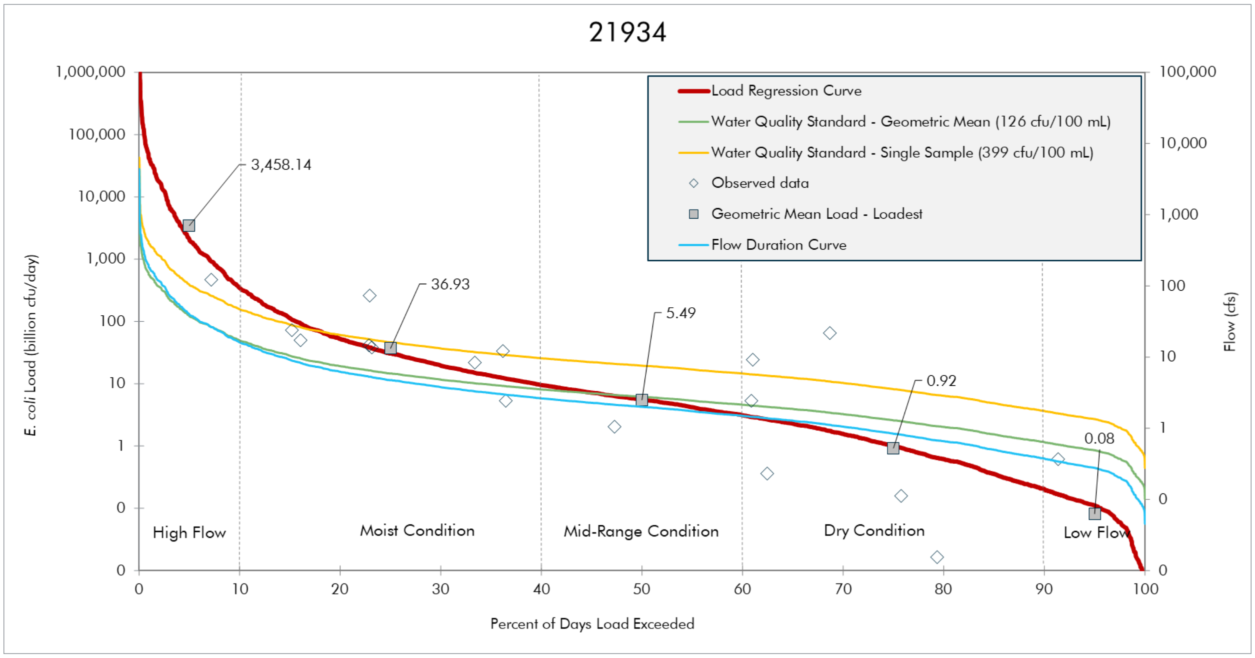

Figure 7. *E. coli* LDC for Station 21934

4.6 LDC Summary

Currently, LDC results for the East Fork of the San Jacinto River have been reviewed internally but have not been subjected to thorough stakeholder analysis. H-GAC staff hope to discuss these results with stakeholders at future partnership meetings and in more focused, one-on-one conversations. This will further refine the assessment to produce data that most accurately reflect fecal bacteria loadings and reduction targets for the East Fork San Jacinto River watershed.

Some of the most important observations to be made from the LDC analysis of East Fork San Jacinto River and its tributaries are:

- *E. coli* loading exceeded the standard in high flow and moist conditions across the watershed.
- *E. coli* loading in other flow conditions varied among sites.

LDC analyses of fecal bacteria loads at all sites throughout the watershed indicated a need for considerable reductions in high flow and moist conditions. Reduction needs at lower levels of flow varied among sites. Sites on the East Fork of the San Jacinto River (11235, 11238, and 17431) require reductions for a wider range of flow levels (high flows through mid-range conditions and occasionally dry conditions) compared to those in the watershed areas of the tributaries (21417 and 21934; reductions only required in high flow and moist conditions). Low flow conditions are within range of the standard at all sites.

SECTION 5: SELECT EVALUATIONS

5.1 Overview

SELECT is a GIS-based tool for estimating potential fecal bacteria loads in a watershed area developed by the Spatial Sciences Laboratory and the Biological and Agricultural Engineering Department at Texas A&M University[4]. This analysis can also determine the relative contributions of fecal indicator bacteria made by a range of potential sources and expresses source contribution data spatially by subwatershed. SELECT analyses result from the combination of land use and land cover data, known source locations (e.g., outfalls), literature assumption values for nonpoint sources (e.g., pet waste, livestock census data, wildlife population density), and stakeholder input. The model does not account for instream loading or other natural processes which may affect fecal bacteria concentrations, nor does it estimate the relative proximity of loading sources to the waterway. Therefore, all references to load estimates in this section refer to potential source loads and not necessarily the actual amounts of fecal bacteria transported into the streams and tributaries of the East Fork San Jacinto River watershed.

To meet the needs of this project, modifications to the original SELECT model were made. The first of these modifications was the use of buffers or zones within a specified distance from a feature (in this case, waterways) to differentiate source load estimations by proximity to streams. Loads generated adjacent to streams are more likely to contribute to instream loading. Because the original SELECT model cannot account for fate and transport of pollutant loads, incorporating buffers around riparian corridors and assigning lower loading rates to sources located in areas outside the buffer minimizes overrepresentation of sources located farther from waterways. Without this consideration, false equivalencies could be interpreted between loads of equal size but different location relative to riparian corridors. For the purposes of this project, 100 percent of the waste generated by sources within a 300-foot buffer zone was assumed to impact waterways. For sources located in areas outside this zone, only 25 percent of the total waste was assumed to be transmitted to the stream network. For sources with no associated spatial data (e.g., deer population density per acre), uniform distribution was assumed for appropriate land uses both inside and outside the buffer boundaries.

The second modification made to the original design of the SELECT model was to estimate fecal bacteria loading changes associated with increased development in five-year increments throughout the next 25 years. By accounting for changes in spatial distribution and magnitude of source loads related to predicted changes in land use between current conditions[5] and the year 2050, reduction estimates can be anticipated at the loading rate observed in the present day and those projected in the future. As with any forecasting effort, a certain level of uncertainty is expected with these predictions especially as they relate to sources assumed to be linked to land use types. For example, in this model, wildlife populations are assumed to decrease as developed area increases within the watershed. This does not account for the adaptability of wildlife to consolidate or redistribute within the watershed area. Further monitoring and assessments of such sources should be incorporated into the management recommendations of the WPP to more accurately account for these factors and counteract this uncertainty.

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[4] Additional information about SELECT can be found at http://ssl.tamu.edu/media/11291/select-aarin.pdf. Information about specific implementation of SELECT for this project can be found in the project modeling QAPP.

[5] At the time of this report, the most updated land use data represents parcel allocations in the year 2020 for Walker, Liberty, Harris, and Montgomery Counties (San Jacinto County not included from regional data).

5.2 SELECT Results

WWTFs

Wastewater utilities serve a number of communities throughout the watershed and occur in various sizes and capacities. For areas outside city boundaries, centralized waste treatment is commonly managed by municipal utility districts and other districts. Considering all types of WWTFs, 10 permitted facilities with discharge monitoring report data are found within the watershed boundary of East Fork San Jacinto River. Size of WWTFs vary throughout the watershed and range between capacities of less than 0.1 millions of gallons per day (MGD) to 1 MGD.

According to the results of a previous data review[6], WWTFs in the East Fork San Jacinto River watershed are not expected to be major contributors to fecal indicator bacteria loading. However, as the risks associated with human waste processed by WWTFs can be considerable in the event of improper treatment or other localized incidents, it is important to consider estimates of potential WWTF loadings in the overall SELECT model. These estimates are derived by multiplying the total discharge capacity of each facility by the state water quality standard for fecal bacteria. As loads were estimated to reflect the impacts of direct outfalls, all results are indicated within the buffer zone surrounding the watershed stream network. For future projections, models continued to estimate fecal bacteria loads at the state standard but adapted flow rates to reflect the projected increase in the number of households within service area boundaries. As many facilities discharge well below their maximum permitted rates, this results in a potential overestimation of fecal bacteria loading from this source. As noted previously, this method is still deemed appropriate for this watershed to account for exceedances or variations throughout daily discharges that could have greater impacts to public health.

In the East Fork San Jacinto River watershed, fecal bacteria loading from WWTFs is more prevalent in the Lower and Middle East Fork San Jacinto River subwatersheds where WWTF densities and sizes are greater (**Figure 8**;

Table 8). When considering the expansion of development throughout the watershed in the coming 25 years, overall fecal bacteria loading in the watershed is expected to increase (**Figure 9**). However, the values of fecal bacteria loads delivered to East Fork San Jacinto River and its tributaries via WWTFs are several orders of magnitude lower than those estimated for other modeled sources described in this section. Therefore, WWTFs are still considered only minor contributors to overall potential fecal bacteria loading in the watershed. These sources are still important to consider in the WPP however, as the health risks associated with any introduction of improperly treated human waste by WWTFs into the watershed are far greater than those associated with other sources[7].

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[6] A more detailed analysis of water quality is discussed further in the Acquired Data Analysis Report for the East Fork San Jacinto Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the East Fork San Jacinto River Modeling Quality Assurance Project Plan) are available for review at https://eastforkpartnership.weebly.com/documents.html.

[7] Results of quantitative microbial risk assessment studies, including work done in the Leon River (https://oaktrust.library.tamu.edu/handle/1969.1/158640) have indicated that sources with equivalent loads may have pronounced differences in expected microbial risk, with human sources being the most potentially problematic.

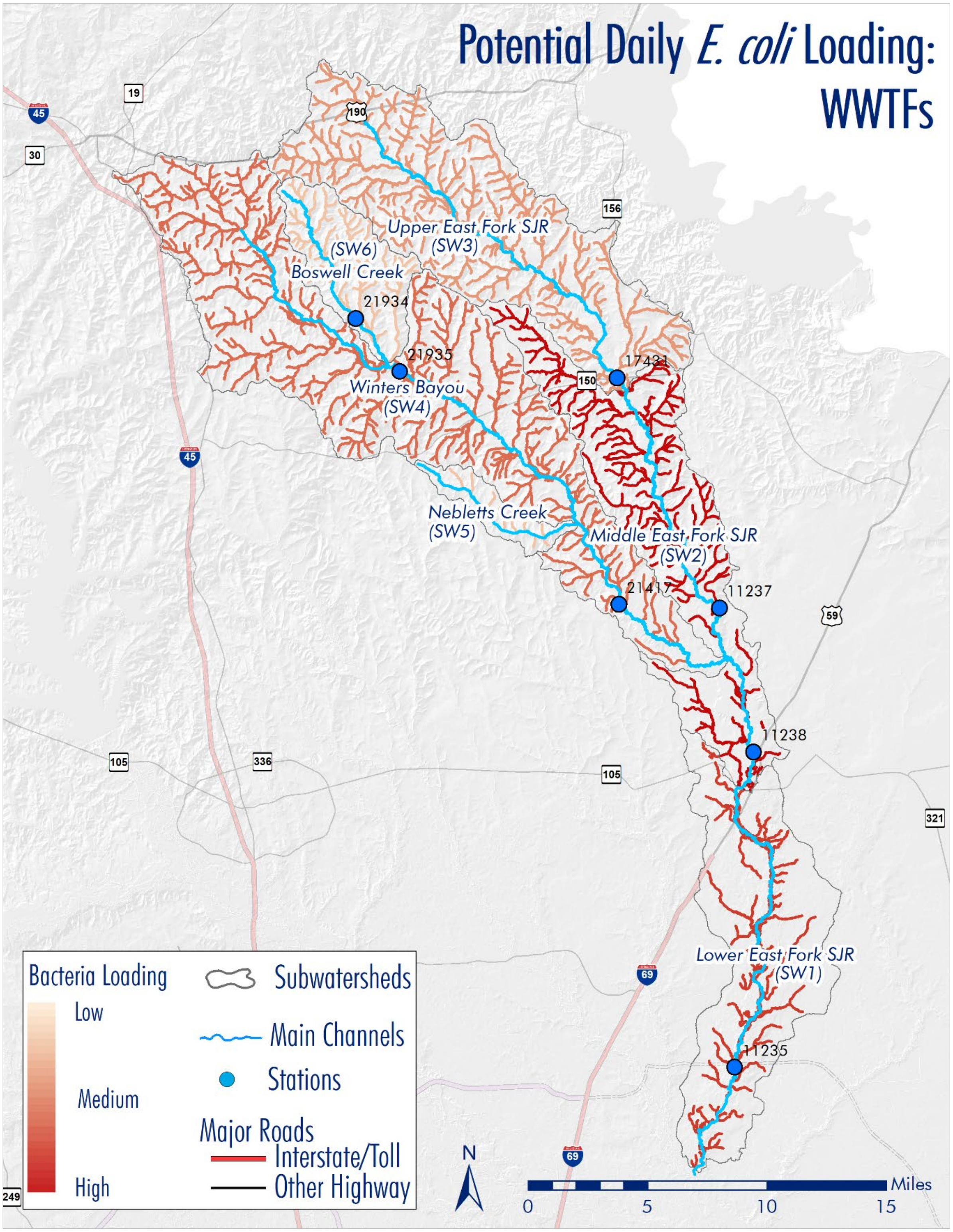

Figure 8. *E. coli* Loadings from WWTFs by Subwatershed

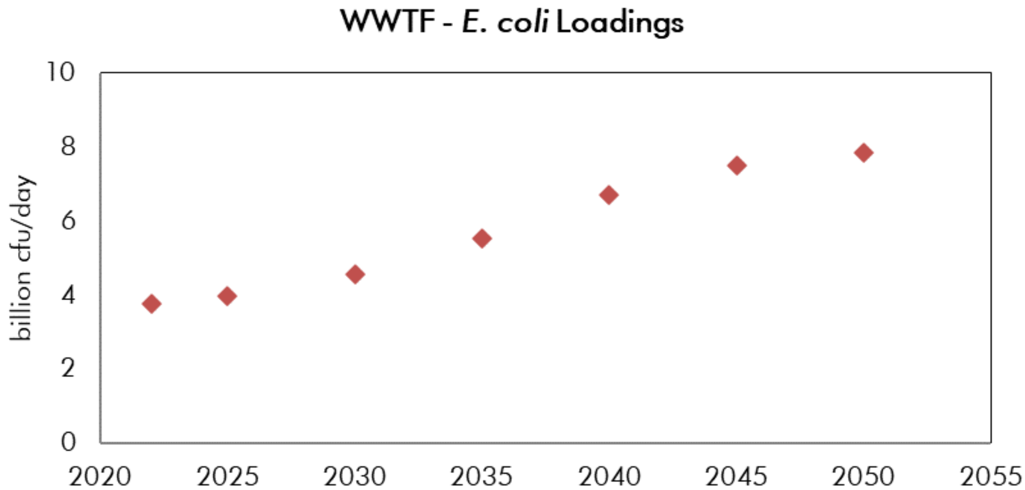

Figure 9. Future *E. coli* Loadings from WWTFs

Table 8. Wastewater Outfalls and Loadings by Subwatershed

Subwatershed	# of Outfalls	Load Estimate in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	5	1.18	31%
Middle East Fork SJR (SW2)	2	1.56	41%
Upper East Fork SJR (SW3)	1	0.05	1%
Winters Bayou (SW4)	2	0.98	26%
Nebletts Creek (SW5)	0	--	--
Boswell Creek (SW6)	0	--	--
Total	**10**	**3.77**	**100%**

OSSFs

While centralized wastewater treatment is common in developed areas, OSSFs are more likely to be used in parts of the watershed outside service area boundaries such as rural communities. OSSFs such as septic and aerobic systems are an efficient and effective way to manage wastewater, however, aging or improperly maintained units run the risk of failing. Significant sources of fecal bacteria can be transmitted to waterways in the event of an OSSF failure.

OSSF distribution throughout the East Fork San Jacinto River watershed was estimated using the spatial data of permitted systems collected under a federal 604(b) grant agreement between H-GAC and TCEQ, and quality assured under the auspices of that contract[8]. Where portions of the watershed overlapped with areas outside the H-GAC region, such as Grimes County, Texas State Data Center population projections were used. This dataset in not comprehensive as some data may be subject to insufficiencies such as a lack of geocoding. This uncertainty is accounted for in the SELECT model through an estimation of any unrecorded or otherwise unpermitted OSSFs in the watershed area based on land use. Unpermitted OSSFs throughout the watershed were estimated by assessing the number of occupied parcels outside service area

[8] Use of this acquired data is detailed in the project modeling QAPP for this project available for review at https://eastforkpartnership.weebly.com/documents.html.

boundaries that were not included in the permitted OSSF database. Loading rates observed from improperly maintained and failed systems were used to estimate total load contribution from OSSFs. Literature values for OSSF failure rates range between 10 and 15%[9]. For the purposes of this report, a conservative estimate of 10% failure rate was applied to the combined total number of permitted units and unpermitted units indicated by the current dataset and for each of the five-year interval projections through 2050. This method has been used for watershed projects in nearby areas but is subject to review in further focused workgroup discussions.

OSSF loadings are highest in the more developed subwatersheds of Lower and Middle East Fork San Jacinto River (**Figure 10**;

Table 9), and are expected to increase through 2050 as residential development increases throughout the watershed (**Figure 11**). These future projections are still based on an assumed 10% failure rate, however, stakeholders may choose to incorporate continued monitoring of these systems in the coming years as OSSF installments age. If systems are found to exceed the 10% failure rate, a new percentage value may be determined. Failure rates among these newly developed systems are likely to be lower as regular maintenance will be required by permit. As improperly maintained OSSFs could also have a negative impact on property values, communities may be more likely to adhere to routine maintenance standards. However, as the health risks associated with any introduction of improperly treated human waste by OSSFs into the watershed are far greater than those associated with other sources, these sources are still important to consider in the WPP.

[9] Reed, Stowe & Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Texas On-site Wastewater Treatment Council.

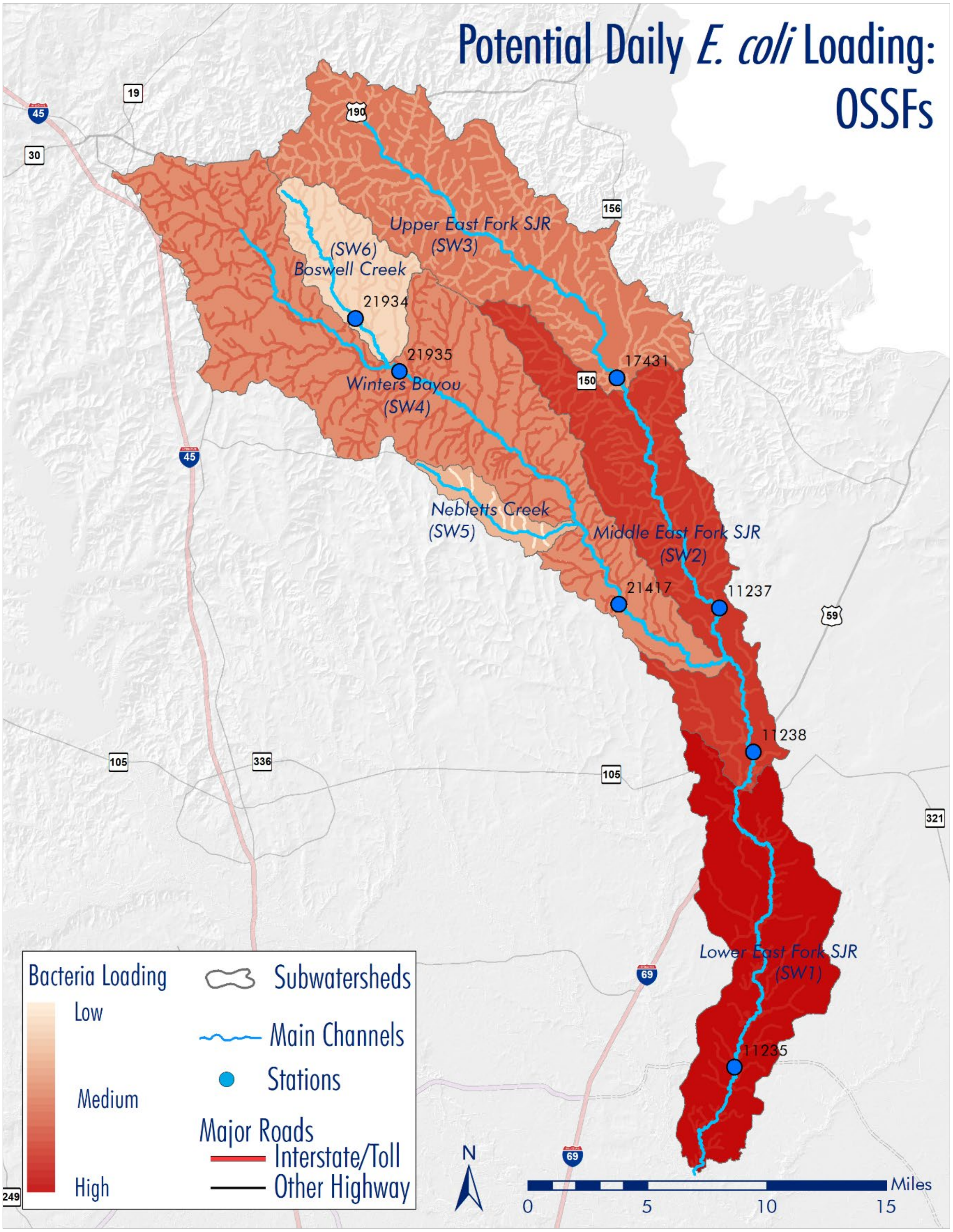

Figure 10. *E. coli* Loading from OSSFs by Subwatershed

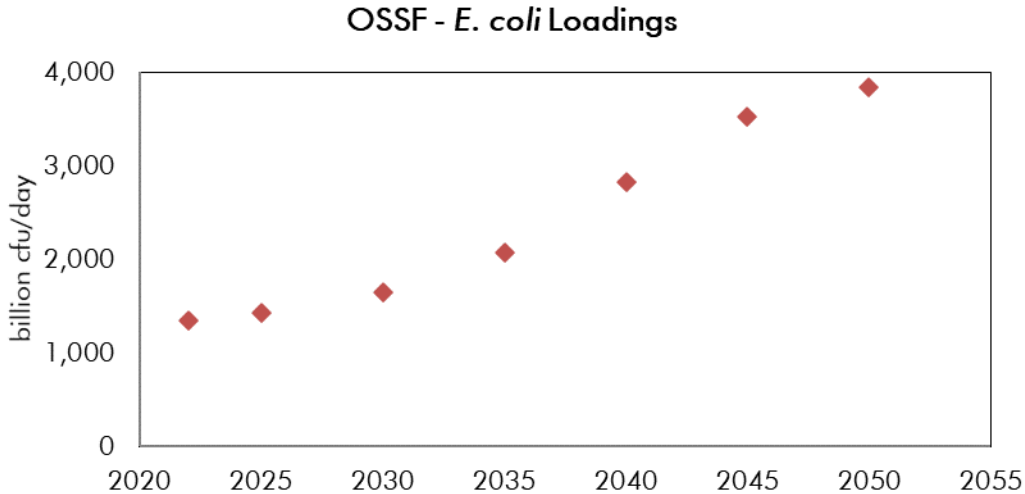

Figure 11. Future *E. coli* Loadings from OSSFs

Table 9. OSSFs and Loadings by Subwatershed

Subwatershed	OSSFs Outside Buffer	OSSFs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	6,560	667	608.44	247.46	63%
Middle East Fork SJR (SW2)	1,186	268	110.00	99.43	16%
Upper East Fork SJR (SW3)	758	140	70.30	51.94	9%
Winters Bayou (SW4)	604	244	56.02	90.52	11%
Nebletts Creek (SW5)	149	0	13.82	0.00	1%
Boswell Creek (SW6)	6	2	0.56	0.74	0%
TOTAL	**9,263**	**1,321**	**859.14**	**490.09**	**100%**

Dogs

Domestic and feral dog populations are significant contributors to fecal bacteria contamination in densely developed areas and are a common source of loading in the greater Houston region. Waste from other domestic pets (e.g., cats) is typically managed through collection in waste receptacles, whereas dog waste is more likely to be deposited directly into the environment.

For SELECT analysis, fecal bacteria loading from dog populations was estimated by assessing pet ownership. Statistical data for Texas established by the American Veterinary Medical Association[10] of 0.6 dogs per household were used in SELECT models. This value was applied to current household data and future projections through 2050. Finally, these estimates were reduced by 20% to account for dog owners practicing proper pet waste management. While this method has been used in other WPP projects with similar land use and drainage areas, stakeholder feedback received during reviews of model results could

[10] As referenced at https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx

lead to a revision of these assumptions based on the specific needs of the East Fork San Jacinto River watershed. Stakeholder insights will be of particular importance to source load estimation of dog waste due to recent efforts to control pet waste throughout the region. Loading estimations could be adjusted to reflect management strategies and community use of waste bags, etc. already underway in the watershed.

Dog ownership, and therefore dog waste, is most densely concentrated in the more developed subwatersheds of Lower and Middle East Fork San Jacinto River (**Figure 12**;

Table 10). As the human population of the watershed increases with expanding residential development in the coming years, dog populations will also increase (**Figure 13**).

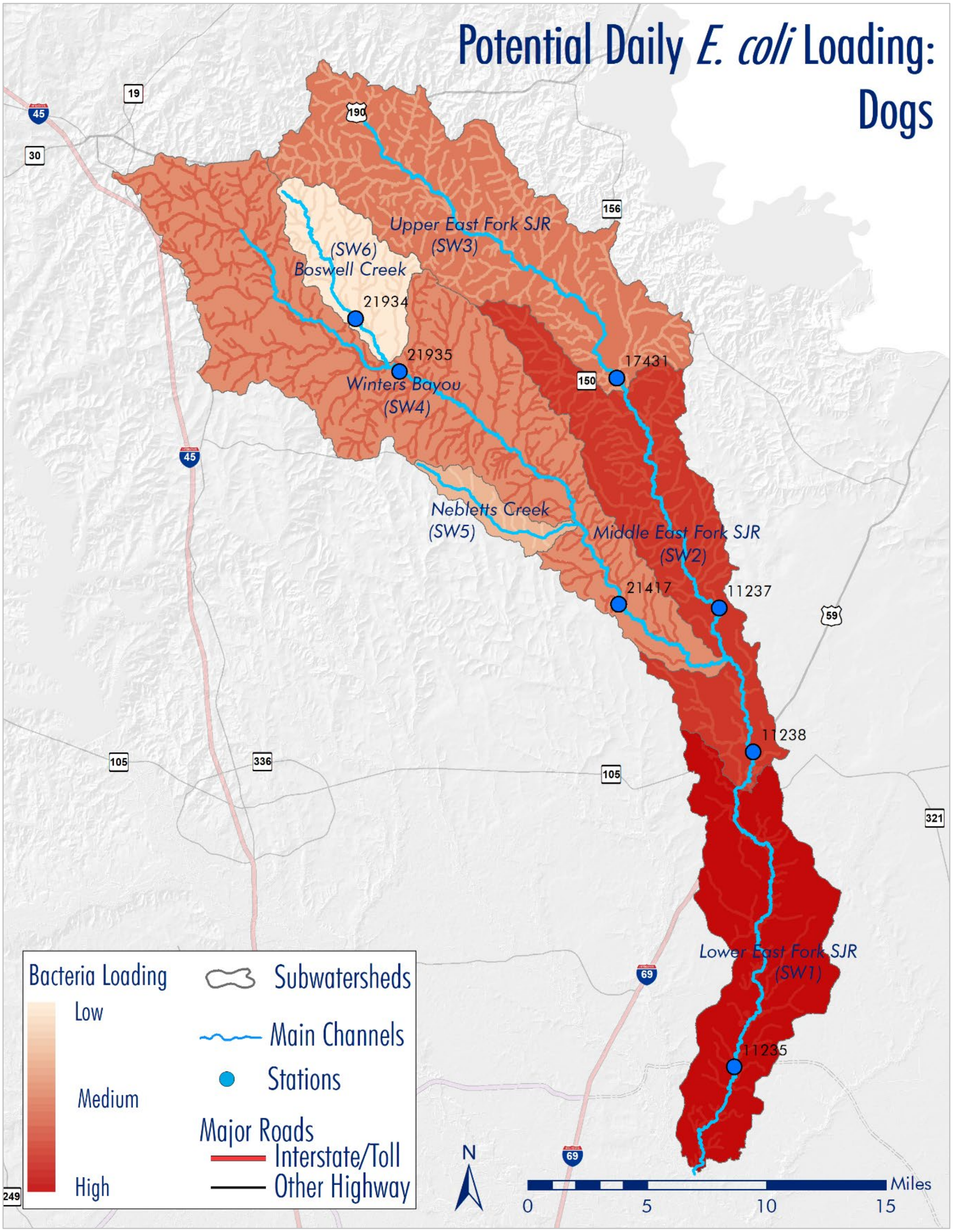

Figure 12. *E. coli* Loading from Dogs by Subwatershed

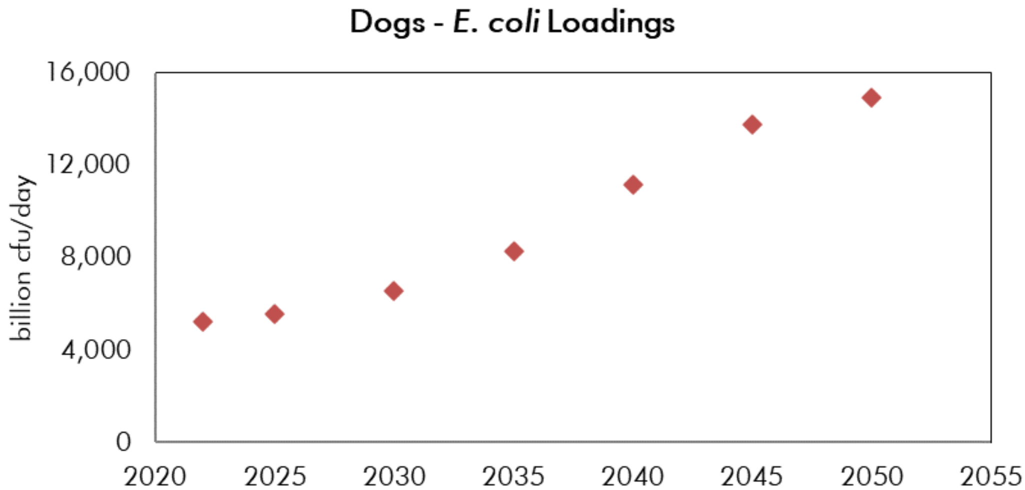

Figure 13. Future *E. coli* Loading from Dogs

Table 10. Dogs and Loadings by Subwatershed

Subwatershed	Dogs Outside Buffer	Dogs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	4,840	412	2,419.80	824.40	62%
Middle East Fork SJR (SW2)	1,299	206	649.50	412.80	20%
Upper East Fork SJR (SW3)	455	84	227.40	168.00	8%
Winters Bayou (SW4)	362	146	181.20	292.80	9%
Nebletts Creek (SW5)	89	11	44.70	22.80	1%
Boswell Creek (SW6)	4	1	1.80	2.40	0%
Total	**7,049**	**860**	**3,524.40**	**1,723.20**	**100%**

Cattle

Agricultural land, grassland, and pastures are most common in the western reaches of the watershed with smaller concentrated areas of these land cover types distributed throughout. National livestock populations including cattle were most recently assessed in a 2017 census by the United States Department of Agriculture. Census data are available by county and are not specific to the watershed area. To estimate cattle in the East Fork San Jacinto River watershed, a ratio of each county's portion of the watershed's acreage in appropriate land cover types to that of the respective county as a whole was applied to agricultural census data from each of the four counties. This approach ensures that the density of cattle in a county's applicable land cover acreage (grassland and pasture/hay) was the same as the density in the watershed's applicable land use acreage. Model results generated from these assumptions will be reviewed with stakeholders for accuracy.

Cattle loads from the Winters Bayou subwatershed are greater compared to other subwatersheds (**Figure 14**; **Table 11**). Projections of future fecal bacteria loading by cattle increase slightly over the next 25 years (**Figure 15**). This slow rate of growth may be affected by land use changes which are predicted to expand development in the East Fork San Jacinto River watershed.

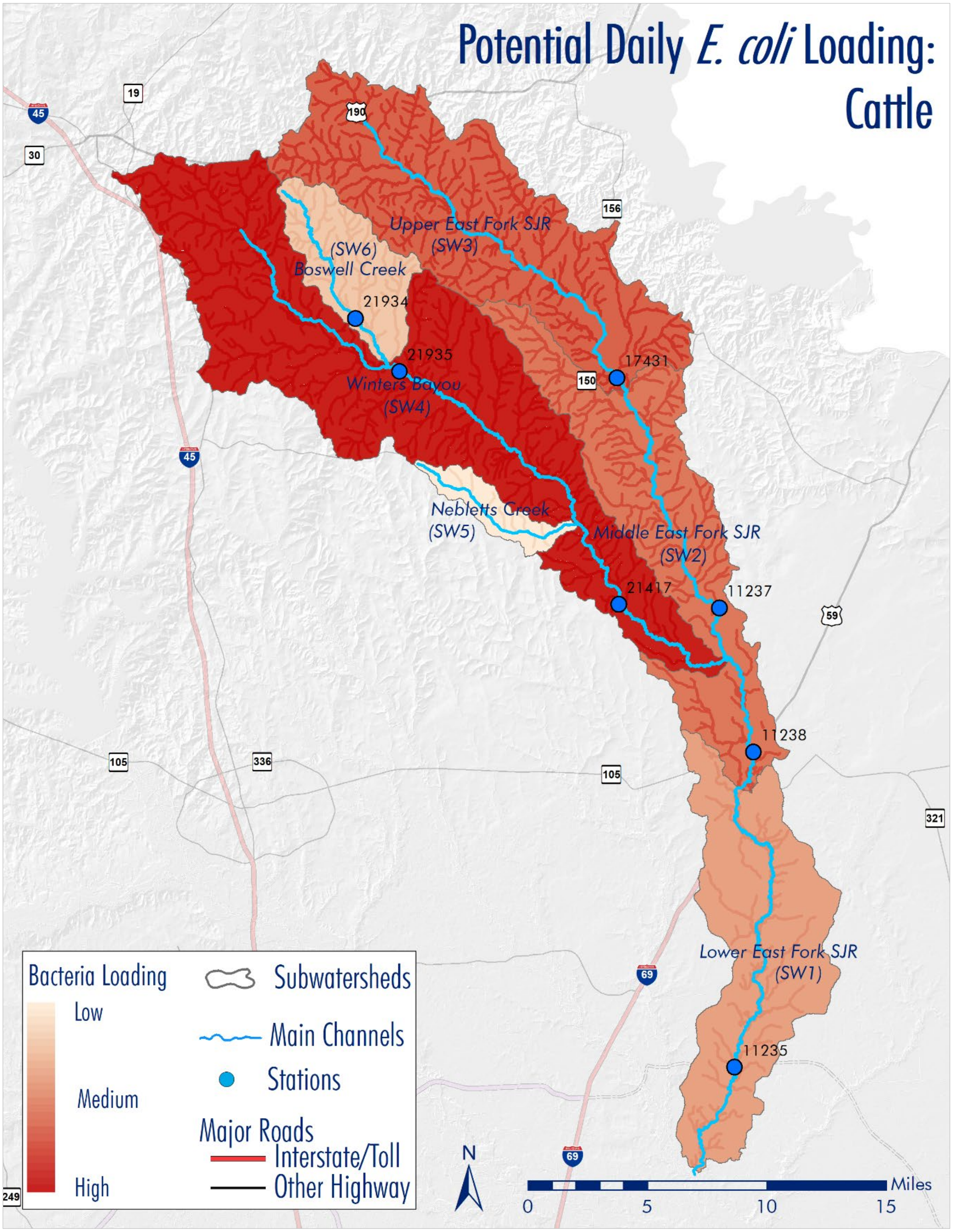

Figure 14. *E. coli* Loading from Cattle by Subwatershed

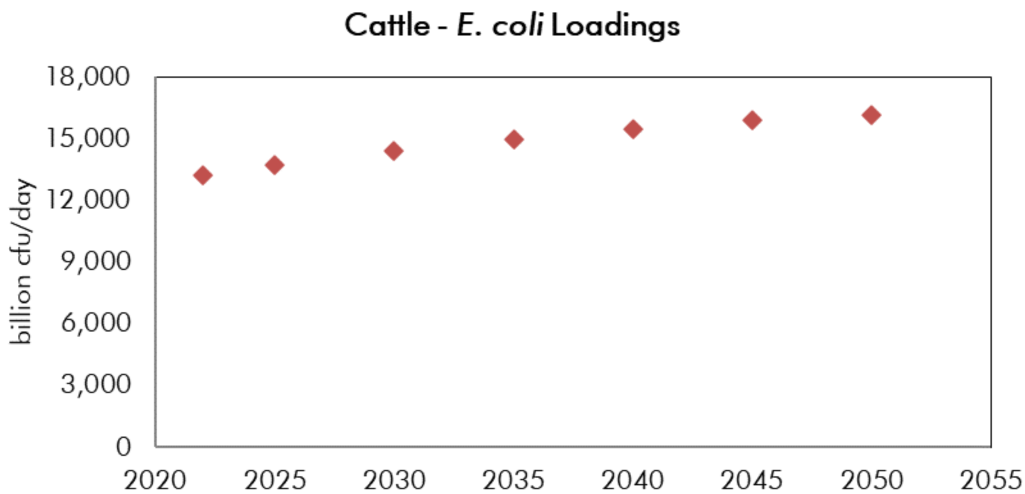

Figure 15. Future *E. coli* Loading from Cattle

Table 11. Cattle and Loadings by Subwatershed

Subwatershed	Cattle Outside Buffer	Cattle Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	723	184	487.89	497.51	8%
Middle East Fork SJR (SW2)	1,081	424	729.85	1,144.00	14%
Upper East Fork SJR (SW3)	1,314	764	886.79	2,061.58	22%
Winters Bayou (SW4)	3,661	1,604	2,471.09	4,331.82	52%
Nebletts Creek (SW5)	107	28	72.12	76.64	1%
Boswell Creek (SW6)	147	129	99.32	348.54	3%
Total	**7,033**	**3,133**	**4,747.06**	**8,460.09**	**100%**

Horses

Similar to cattle, horse population estimates were calculated based on agricultural census data modified by the ratio of watershed area of relevant land use types to total county area. This method assesses only the horses designated for livestock use in the watershed. Horses owned for recreational purposes may not be well represented by these estimates. Discussions with watershed stakeholders are ongoing and may result in a revised method to more accurately reflect horse populations in the East Fork San Jacinto River watershed.

As with cattle, horse bacteria loading is high in the Winters Bayou subwatershed but is even greater in the Upper East Fork San Jacinto River watershed (**Figure 16**;

Table 12). Loading over time is not predicted to change greatly between 2022 and 2050 (**Figure 17**). Stakeholder feedback will be needed to determine whether any adjustments need to be made to these assumptions.

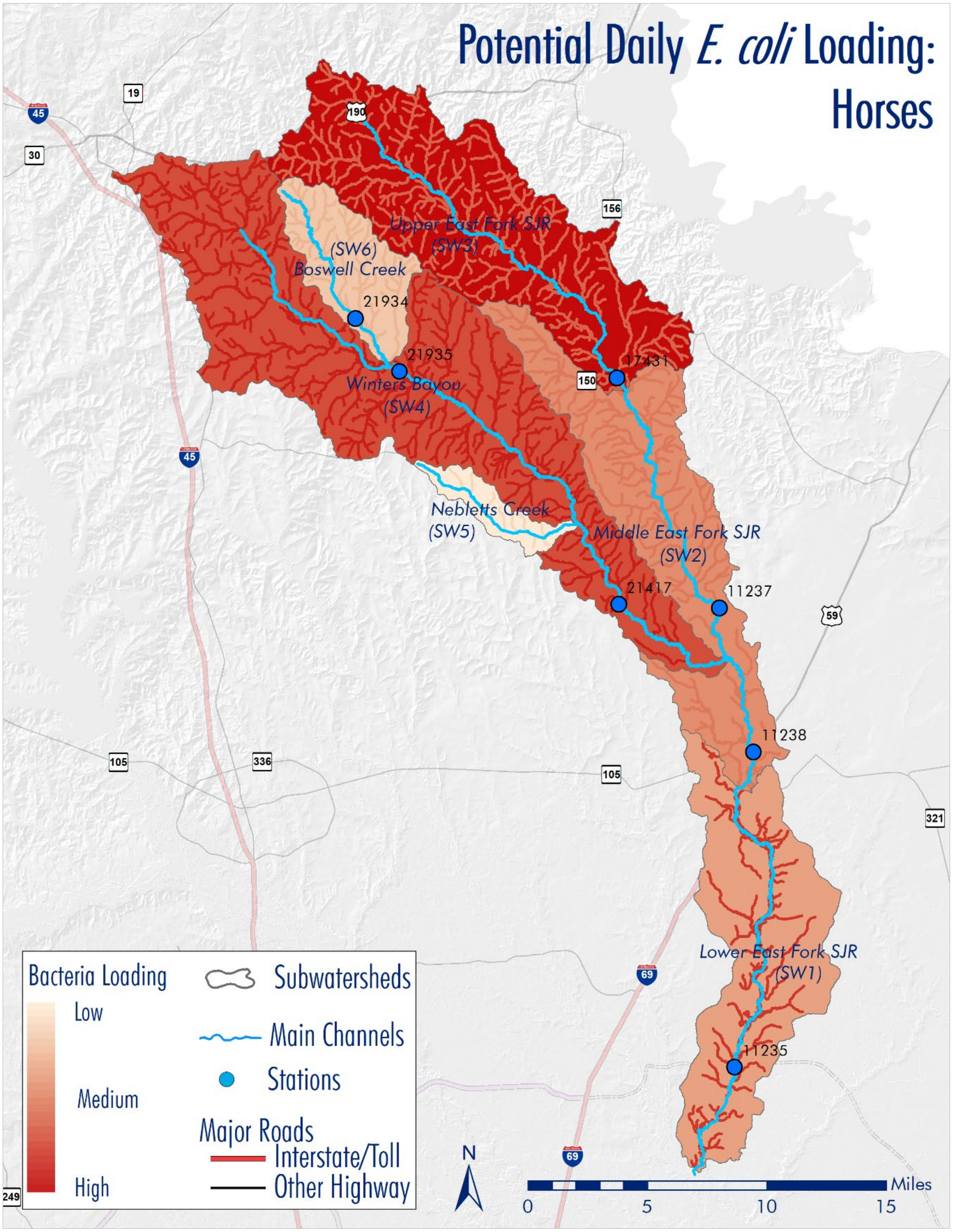

Figure 16. *E. coli* Loading from Horses by Subwatershed

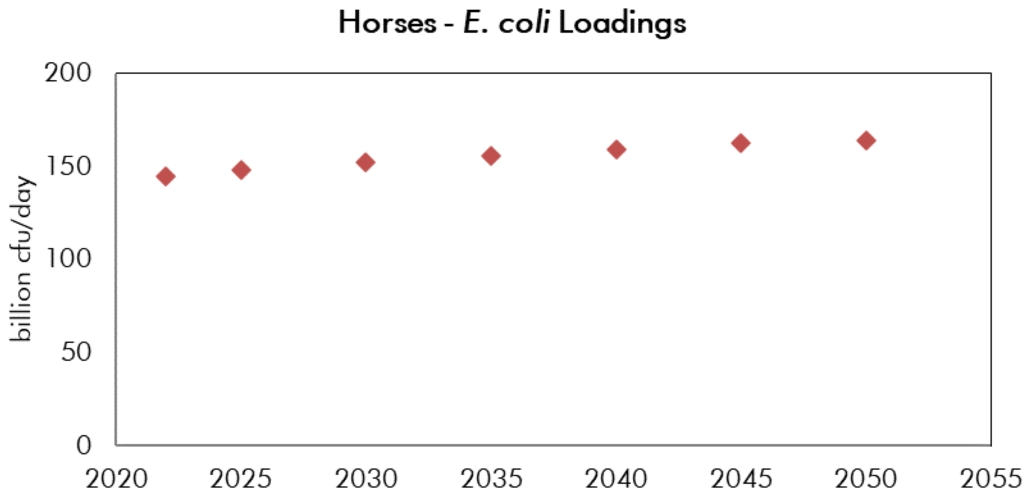

Figure 17. Future *E. coli* Loadings from Horses

Table 12. Horses and Loadings by Subwatershed

Subwatershed	Horses Outside Buffer	Horses Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	68	17	3.56	20.41	17%
Middle East Fork SJR (SW2)	101	40	5.32	8.34	9%
Upper East Fork SJR (SW3)	123	72	38.14	15.03	37%
Winters Bayou (SW4)	343	150	18.02	31.59	34%
Nebletts Creek (SW5)	10	3	0.53	0.56	1%
Boswell Creek (SW6)	14	12	0.72	2.54	2%
Total	**659**	**294**	**66.29**	**78.47**	**100%**

Sheep and Goats

Sheep and goat populations represent a smaller portion of the livestock in the watershed, but still retain a presence in rural areas. Both animal populations are grouped into a single statistic in the agricultural census. To estimate the size of these populations, the same method used for cattle and horses was applied to agricultural census data for sheep and goats. Assessment and revision of the initial population estimates may be explored after further discussion with stakeholder groups.

Sheep and goat bacteria loading bears a strong special similarity to cattle bacteria loading with the highest concentration occurring in the Winters Bayou subwatershed (**Figure 18**;

Table 13). This is likely due to the highest percentage of agricultural land of any of the subwatersheds occurring in the drainage area for Winters Bayou. As with other agricultural animals, growth in sheep and goat populations is expected increase slightly, though the rate will slow over time as development expands (**Figure 19**).

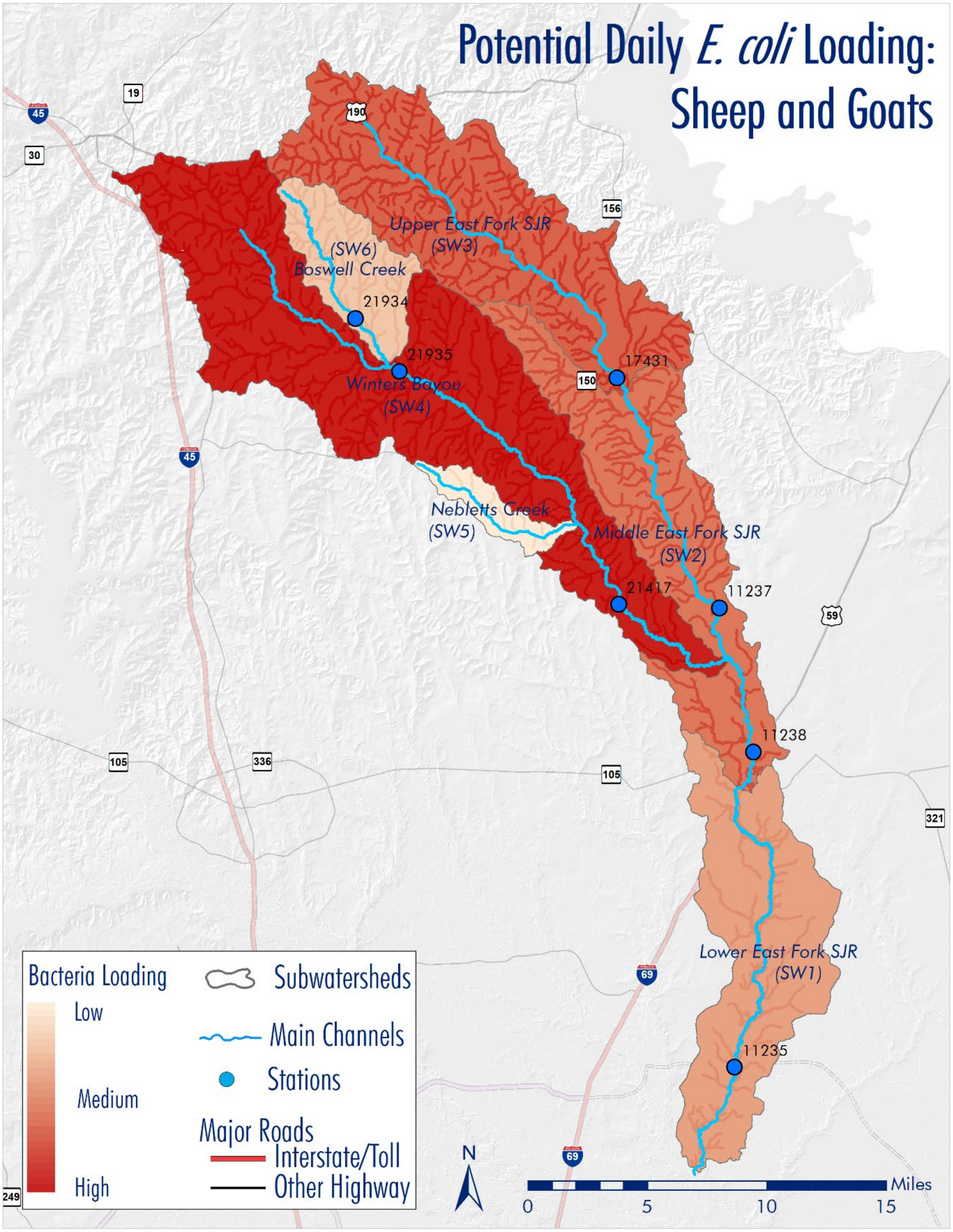

Figure 18. *E. coli* Loadings from Sheep & Goats by Subwatershed

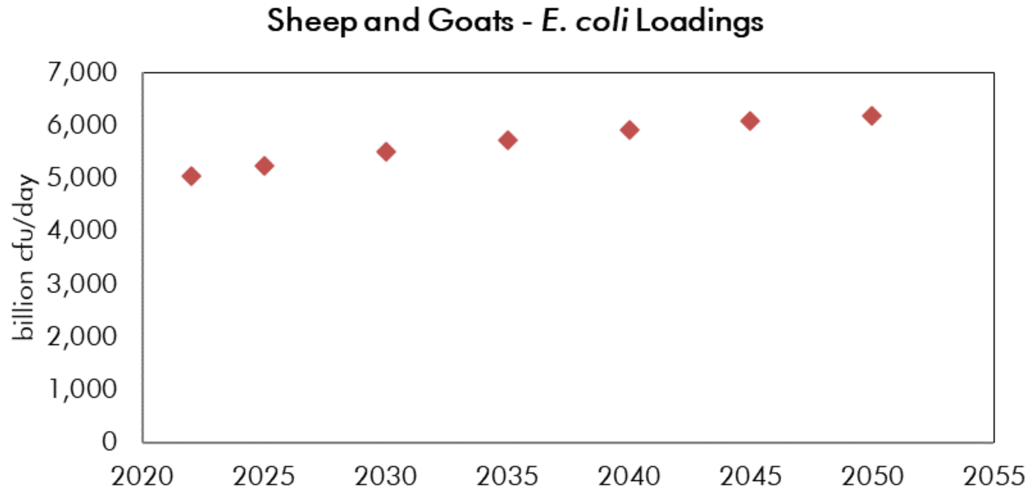

Figure 19. Future *E. coli* Loadings from Sheep & Goats

Table 13. Sheep & Goats and Loadings by Subwatershed

Subwatershed	Sheep & Goats Outside Buffer	Sheep & Goats Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	83	21	186.18	189.85	8%
Middle East Fork SJR (SW2)	124	49	278.52	436.56	14%
Upper East Fork SJR (SW3)	150	87	338.41	786.71	22%
Winters Bayou (SW4)	419	184	942.99	1,653.05	52%
Nebletts Creek (SW5)	12	3	27.52	29.24	1%
Boswell Creek (SW6)	17	15	37.90	133.01	3%
Total	**805**	**359**	**1,811.52**	**3,228.42**	**100%**

Deer

Forests and open grasslands in the less developed areas of the watershed provide ample habitat area for white-tailed deer. However, deer are among the few species that are adaptable to the encroachment of developed areas. Loss of natural areas may lead deer to explore larger lots of suburban and light urban development as alternative habitat. Because of this, natural areas and open and low intensity developed areas were considered as possible deer habitat for the purposes of load estimation. Assessment and revision of the initial population estimates may be explored after further discussion with stakeholder groups. Resource Management Unit population density data accessed from the Texas Parks and Wildlife Department assuming one deer for every 40.2 acres of forest, shrubland and open developed areas was used to estimate deer populations and their associated fecal bacteria loading potential. In low intensity developed areas, deer density was assumed to be one deer for every 80.4 acres. With this approach, population dynamics are not well represented with respect to movements between land cover types and possible increases in density of natural areas after the built environment extends into previously undeveloped spaces.

Estimated deer bacteria loadings were highest in Winters Bayou and Upper East Fork San Jacinto River subwatersheds (**Figure 20**;

Table 14). Despite their ability to adapt to more developed land areas when faced with the loss of natural habitat, deer populations in the East Fork San Jacinto River watershed are predicted to remain stable over time (**Figure 21**). As the SELECT model only accounts for gains and losses of fecal bacteria load pressures, migration between parcels could be underestimated. Further discussions with stakeholders will focus on assessing the accuracy of these estimations and what modifications may be appropriate for data adjustment.

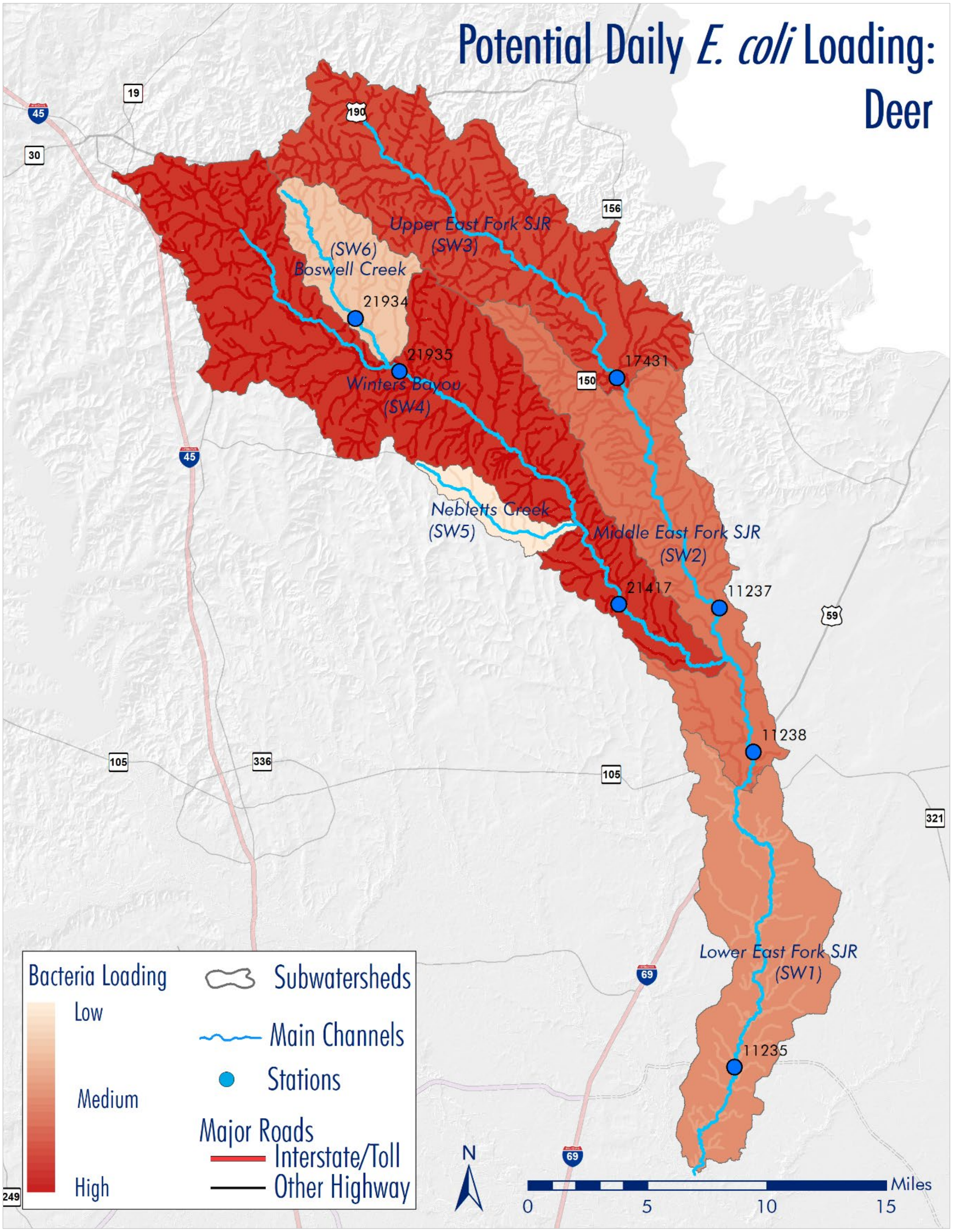

Figure 20. *E. coli* Loadings from Deer by Subwatershed

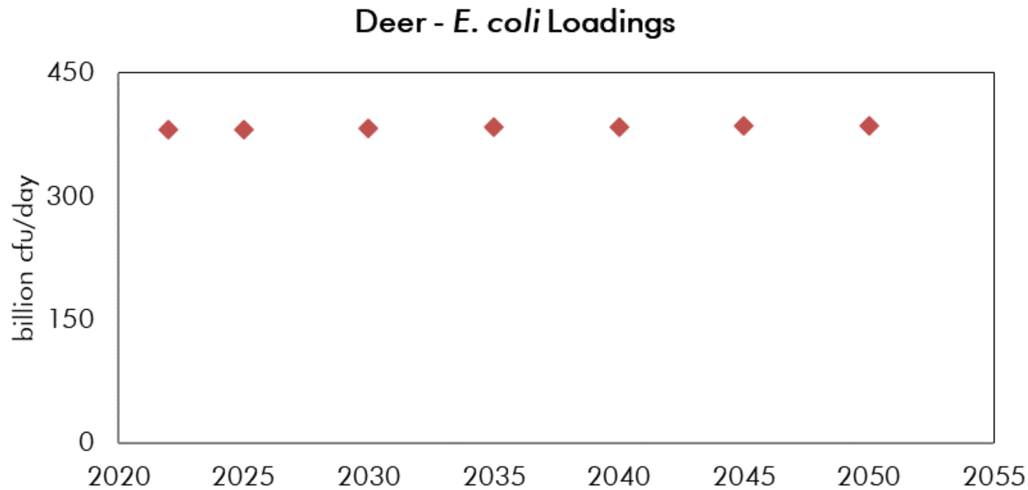

Figure 21. Future *E. coli* Loadings from Deer

Table 14. Deer and Loadings by Subwatershed

Subwatershed	Deer Outside Buffer	Deer Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	622	117	27.19	20.41	13%
Middle East Fork SJR (SW2)	642	217	28.07	37.96	17%
Upper East Fork SJR (SW3)	872	351	38.14	61.44	26%
Winters Bayou (SW4)	1,221	450	53.40	78.74	35%
Nebletts Creek (SW5)	89	22	3.91	3.93	2%
Boswell Creek (SW6)	241	98	10.56	17.06	7%
Total	**3,687**	**1,255**	**161.27**	**219.54**	**100%**

Feral Hogs

In the Houston-Galveston region feral hogs (*Sus scrofa*) are an invasive species that negatively impact agriculture, wildlife species and their habitats, and human landscapes. Efforts to control feral hogs have been carried out by communities within the East Fork San Jacinto River watershed that have already recognized the environmental pressures associated with their populations. Feral hogs are of particular concern as carriers of diseases that can be dangerous to domestic livestock, pets, and humans. These animals are known to use land around waterways as shelter and transportation corridors between food resources and can generate large volumes of waste where they concentrate.

Though they occur in the highest densities along riparian corridors and other natural areas, feral hogs are pervasive and can be found in all land cover types aside from developed areas and open water. Population density estimates used in the SELECT model for feral hog source loads referenced land cover types in the watershed area are based on AgriLife literature values[11]. In areas of high and medium development and

[11] As referenced at http://agrilife.org/feralhogs/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf

open water, hog densities of zero were assumed. In areas of low intensity development and developed open spaces, 8.9 hogs per square mile were assumed. In bare land, cultivated areas, and pasture, that density increased to 12.7 hogs per square mile. Grasslands, forests, shrublands, and wetland areas were assumed to have an even higher density of 16.4 hogs per square mile. Due to this association with land cover, future projections of feral hog loads will be tied to changes in development.

Potential fecal bacteria loading by feral hogs was estimated to be higher in the Winters Bayou subwatershed and in riparian areas north of the Lower East Fork subwatershed (**Figure 22**;

Table 15). Future projections of feral hog loads predict little change in magnitude as time progresses (**Figure 23**). However, the SELECT model does not account for the adaptability of feral hog populations that have anecdotally been observed to redistribute or condense when faced with the loss of their preferred habitats. Therefore, without literature support or evidence from local stakeholders, the estimates presented in this SELECT model should be considered conservative.

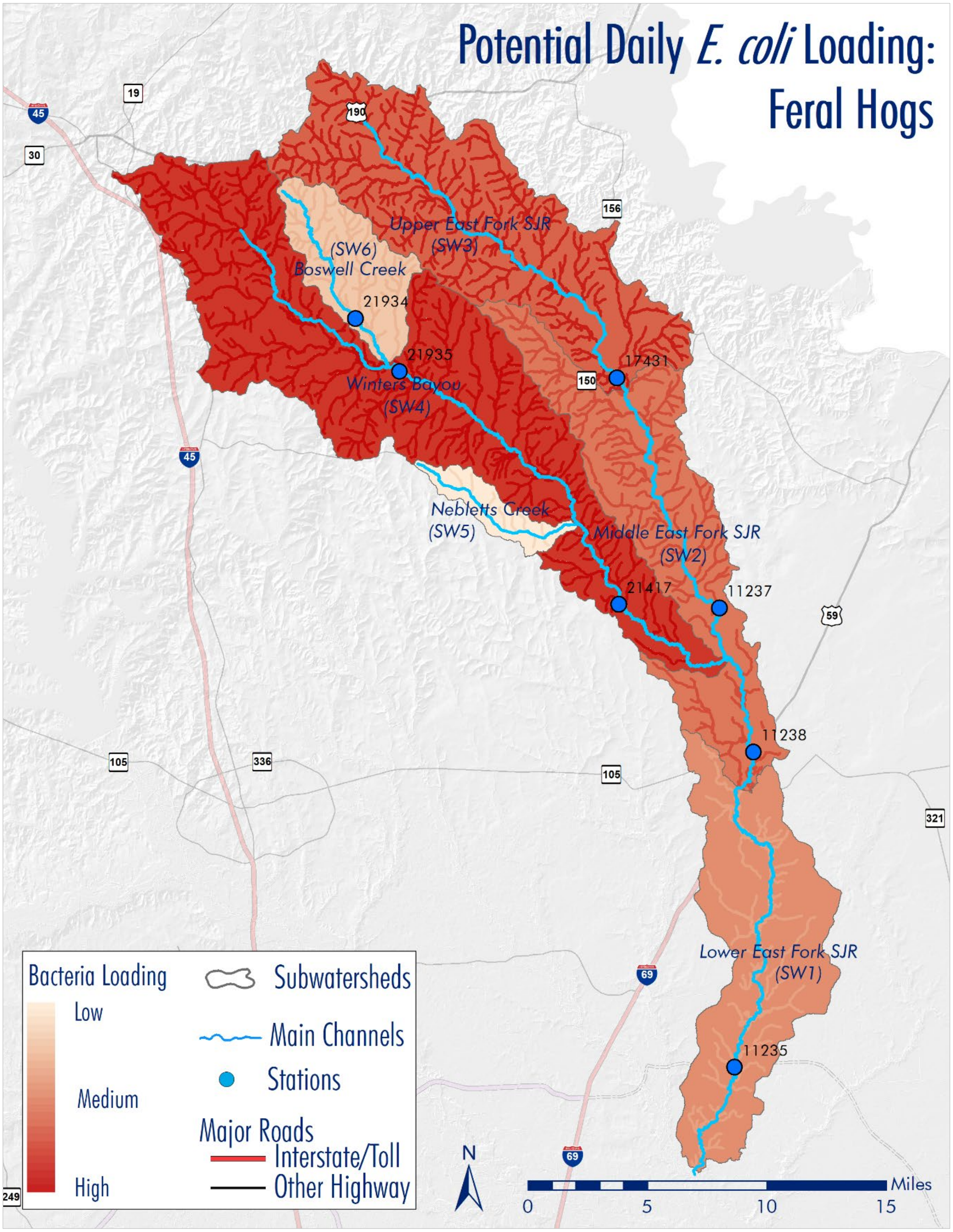

Figure 22. *E. coli* Loadings from Feral Hogs by Subwatershed

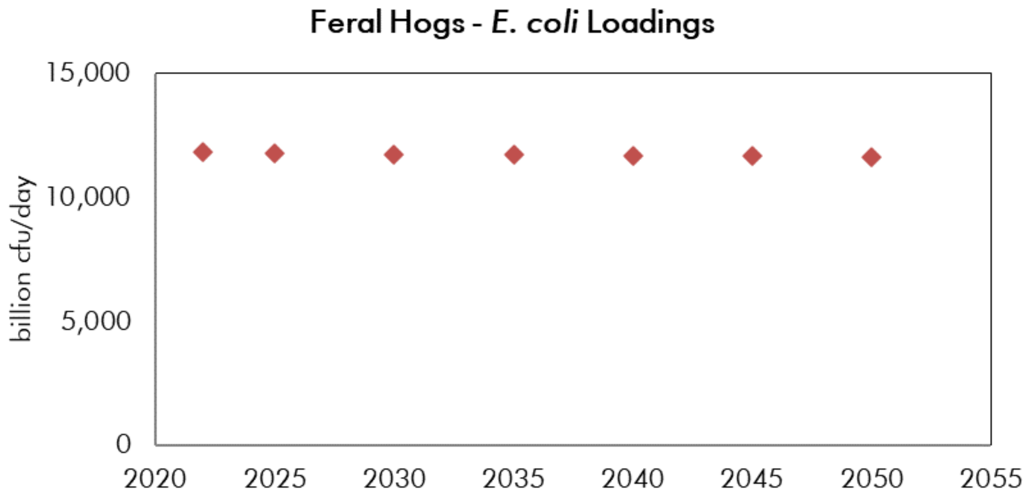

Figure 23. Future *E. coli* Loadings from Feral Hogs

Table 15. Feral Hogs and Loadings by Subwatershed

Subwatershed	Feral Hogs Outside Buffer	Feral Hogs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Lower East Fork SJR (SW1)	731	156	813.00	692.28	13%
Middle East Fork SJR (SW2)	755	274	839.59	1,221.34	17%
Upper East Fork SJR (SW3)	988	431	1,098.77	1,918.63	26%
Winters Bayou (SW4)	1,453	581	1,616.45	2,583.93	35%
Nebletts Creek (SW5)	101	28	112.00	122.44	2%
Boswell Creek (SW6)	261	114	290.59	507.56	7%
Total	**457**	**161**	**4,770.40**	**7,046.17**	**100%**

Other Sources

Most of the project's understanding of fecal bacteria loading in the East Fork San Jacinto River watershed is based on the modeled sources described above. However, many other sources are recognized as contributors to the total fecal bacteria load that are less easily characterized. Further explanation regarding how those sources will be accounted for in the WPP development process are described below.

Human Waste – Direct Deposition

In other watershed projects, potential impacts from homeless communities and areas not serviced by centralized or localized wastewater treatment were considered. Further discussion with area stakeholders is needed to assess the extent of these impacts in the East Fork San Jacinto River watershed.

Land Deposition of Sewage Sludge

If improper use of manure spreading, or violations of sludge application have occurred in the watershed area, action would be required to intervene and reduce the resulting fecal bacteria loading impacts. However, these impacts would likely be addressed in best management practices for agricultural sources of pollution.

Sanitary Sewer Overflows (SSOs)

Though SSOs occur episodically, they represent a high-risk vector for fecal bacteria contamination because they can have concentrations of fecal bacteria several orders of magnitude higher than treated effluent. Untreated sewage can contain large volumes of raw fecal waste, making it a significant health risk where SSOs are sizeable or chronic issues. Events are self-reported and may vary in quality. Descriptions of frequencies, causes, durations, and volumes of SSOs may be subject to logistical inadequacies such as unknown duration of discharge, and inability to accurately gage discharge volume. Actual SSO volumes and incidences are generally expected to be greater than reported due to these fundamental challenges.

After reviewing data compiled in SSO reports submitted by permit holders in the East Fork San Jacinto River watershed[12], SSO events were not found to follow any specific spatial, seasonal, or annual pattern. Weather events accounted for the highest number of events and overflow volume respective to the other general categories of malfunctions, blockages, and unknown causes.

Due to the episodic nature and spatial inconsistency of SSO events, fecal bacteria loads from these sources are not expected to have an appreciable long-term impact on the overall loading for the watershed and were excluded from SELECT model analysis. Though the estimations of SSO impacts in this watershed are not represented by SELECT models, they are no less important to consider in the overall assessment of fecal bacteria loading. The most extreme method of estimating fecal bacteria loads from SSOs would be to calculate loading based on EPA literature values[13] suggested for general causes related to each event multiplied by the highest observed volumes of discharge recorded for each cause. A more conservative method would be to calculate the average daily volume of discharge and use that as the multiplier for cause related load estimates. In other area watershed projects, stakeholders elected to refrain from the aforementioned calculations and treat SSOs as a separate, high-priority item for inclusion in the management strategies outlined in the WPP. SSO data regarding unique events impacting stream segments within the watershed area over the most recent five years of reports provided by TCEQ were used in these assessments. This approach could be explored in the East Fork San Jacinto River watershed according to the decision making of the stakeholder group.

Concentrated Animal Feeding Operation (CAFO)

No active CAFOs are in operation within the East Fork San Jacinto River watershed.

Birds

The greater Houston area is well known as part of the great Central Flyway migration path used by various bird populations. Many migratory bird species only utilize the land area for short periods of time while in transit, but migratory waterfowl and resident species represent longer-term populations, especially in coastal marshes. Similar watershed projects have evaluated the potential impact of waterfowl in terms of duration, potential fecal bacteria load, and other considerations,

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[12] A more detailed analysis of water quality is discussed further in the Acquired Data Analysis Report for the East Fork San Jacinto Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the East Fork San Jacinto River Modeling Quality Assurance Project Plan) are available for review at https://eastforkpartnership.weebly.com/documents.html.

[13] As referenced at https://www3.epa.gov/npdes/pubs/csossoRTC2004_AppendixH.pdf.

and found them to not be significant sources to be modeled. Colonial birds such as swallows have been identified by other watershed projects as potential sources of fecal bacteria load. Unfortunately, little or no data is available to characterize the impacts of fecal bacteria loading from colonial bird sources or to implicate colonial bird influenced fecal bacteria loading as significant health risks to the watershed community. Stakeholder knowledge will be critical to an improved understanding of the dynamics and magnitude of avian populations. Beyond lack of data, relatively small fecal bacteria loads and health risks associated with bird waste compared to human sources, and general lack of management strategies available to deal with wild birds have limited the emphasis of this source as a meaningful component of management efforts in similar projects.

Bats

Though bats are present in the watershed area, only large colonies of these animals are estimated to have an appreciable impact on water quality. No known nesting sites of significant size or density have been indicated in the East Fork San Jacinto River watershed.

Other Wildlife

Specific data for wildlife such as coyotes, opossums, rodents, wild cats, skunks, raccoons, and other mammals is not widely available. Similar watershed projects have recognized these wildlife animals as potentially appreciable contributors to fecal bacteria loads, but lacked a reasonable method for quantifying their potential impacts. One method of improving understanding of wildlife impacts in the East Fork San Jacinto River watershed would be to implement fecal bacteria source tracking or assessments of genetic material found in waterways to identify species depositing fecal waste in and around streams. Data collected with this method in other watersheds showed that wildlife impacts are significant[14] and should be incorporated into fecal bacteria reduction strategies. As no such data are presently available for the East Fork San Jacinto River watershed, the understanding of wildlife species in this area will be largely informed by anecdotal information provided by stakeholders and general estimations decided by stakeholder input. In nearby Spring and Cypress Creek, wildlife impacts were assumed to be equivalent to a conservative 10% of the other modeled loads assessed in the watershed. The value was generated by finding the total for all other sources in all subwatersheds, setting that total as 90% of the total load, and then assuming wildlife to be the other 10%. After reviewing modeled results with stakeholders, this percentage may be adjusted according to the specific needs of the watershed.

Cats

Domestic dogs are included in the SELECT model analysis as a concern of particular interest to the watershed due to the likelihood of improperly managed dog waste deposited outdoors making its way to streams via runoff. Domestic cat waste management is typically handled indoors and restricted to litter boxes. Therefore, pet waste from cats was not estimated as part of this project. Feral cats, however, can be a local source when found in sufficiently dense urban populations, though very little data exists to quantify these impacts. Generally, impacts from feral cats may be accounted for in other loading assumptions such as diffuse urban stormwater or as part of the impacts from other wildlife.

[14] For example, bacteria source tracking completed by Texas A&M University for Attoyac Bayou showed *E. coli* from wildlife at greater than 50% of load across flow conditions (https://oaktrust.library.tamu.edu/handle/1969.1/152424) and a similar analysis (https://oaktrust.library.tamu.edu/handle/1969.1/149197) conducted for the Lampasas and Leon Rivers showed comparable results.

Dumping

Illegal dumping is not typically a widespread or appreciable contributor to fecal bacteria loads in watersheds as these events occur locally and/or episodically. This factor may still be important for stakeholders to consider addressing in the WPP in terms of aesthetic and other regulatory issues.

Sediment

Sedimentation has been identified by stakeholders in nearby watersheds including Spring and Cypress Creek. With increased availability of sediment and other suspended solids in waterways, fecal bacteria may benefit from increases in substrate and decreases in insolation that prevent natural processes of die-off. Sedimentation can also impact dissolved oxygen levels and have pronounced hydrologic impacts on flow. If stakeholders indicate similar concerns for the East Fork San Jacinto River watershed, these concerns will be addressed in the WPP.

5.3 Summary of Results

SELECT analyses indicated the highest loads from the total mix of modeled sources are concentrated in the Winters Bayou subwatershed because of pressures from agriculture and invasive feral hogs (**Table 16**). There is also a pronounced concentration of loading in the Lower East Fork San Jacinto River subwatershed associated with pressures related to development, including dog waste and OSSF discharge (**Table 16**). Future projections for increased overall fecal bacteria loading throughout the watershed are also important to consider in the development of a WPP (

Table 17). Without taking action to reduce fecal bacteria sources in the watershed, loads will continue to increase between 2022 and 2050 (**Figure 24**), with dogs having the largest estimated increase (**Figure 25**; **Figure 26**). Stakeholder input will be crucial for determining whether less traditional load estimation approaches for wildlife and other sources yield accurate and defensible results for the watershed. Modeled predictions may be adjusted after review with stakeholders at partnership meetings, focused workgroups, and one-on-one conversations.

Table 16. Daily Average *E. coli* Loads in Billion cfu/day by Source and Subwatershed, 2022

Source	Lower East Fork SJR (SW1)	Middle East Fork SJR (SW2)	Upper East Fork SJR (SW3)	Winters Bayou (SW4)	Nebletts Creek (SW5)	Boswell Creek (SW6)	% Total Load
OSSFs	855.90	209.43	122.24	146.55	13.82	1.30	3%
WWTFs	1.18	1.56	0.05	0.98	0.00	0.00	0%
Dogs	3,244.20	1,062.30	395.40	474.00	67.50	4.20	13%
Cattle	985.40	1,873.85	2,948.37	6,802.92	148.76	447.86	32%
Horses	23.97	13.67	53.18	49.61	1.08	3.27	0%
Sheep & Goats	376.04	715.08	1,125.12	2,596.04	56.77	170.91	12%
Deer	47.60	66.03	99.58	132.14	7.83	27.63	1%
Other Wildlife	782.17	666.98	862.37	1,600.29	58.91	161.48	10%
Feral Hogs	1,505.27	2,060.94	3,017.40	4,200.39	234.44	798.14	29%

Table 17. Daily Average *E. coli* Loads in Billion cfu/day by Source for All Milestone Years

Source		2022	2025	2030	2035	2040	2045	2050
Human Waste	OSSFs	1,349.23	1,428.81	1,651.04	2,070.37	2,824.33	3,528.30	3,841.61
	WWTFs	3.77	3.95	4.56	5.52	6.71	7.49	7.86
Pets	Dogs	5,247.60	5,581.20	6,541.20	8,265.60	11,144.10	13,762.80	14,931.90
Livestock	Cattle	13,207.16	13,728.69	14,388.43	14,971.42	15,472.74	15,911.28	16,166.86
	Horses	144.78	148.16	152.33	156.01	159.38	162.33	163.96
	Sheep & Goats	5,039.95	5,238.96	5,490.73	5,713.20	5,904.51	6,071.86	6,169.39
Wildlife	Deer	380.82	381.75	382.80	383.82	385.00	386.24	386.55
	Other Wildlife	4,132.21	4,254.83	4,483.85	4,808.40	5,286.38	5,720.57	5,923.03
Invasives	Feral Hogs	11,816.57	11,781.98	11,743.53	11,709.68	11,680.62	11,654.86	11,639.13
TOTAL		**41,322.09**	**42,548.34**	**44,838.47**	**48,084.02**	**52,863.77**	**57,205.71**	**59,230.29**

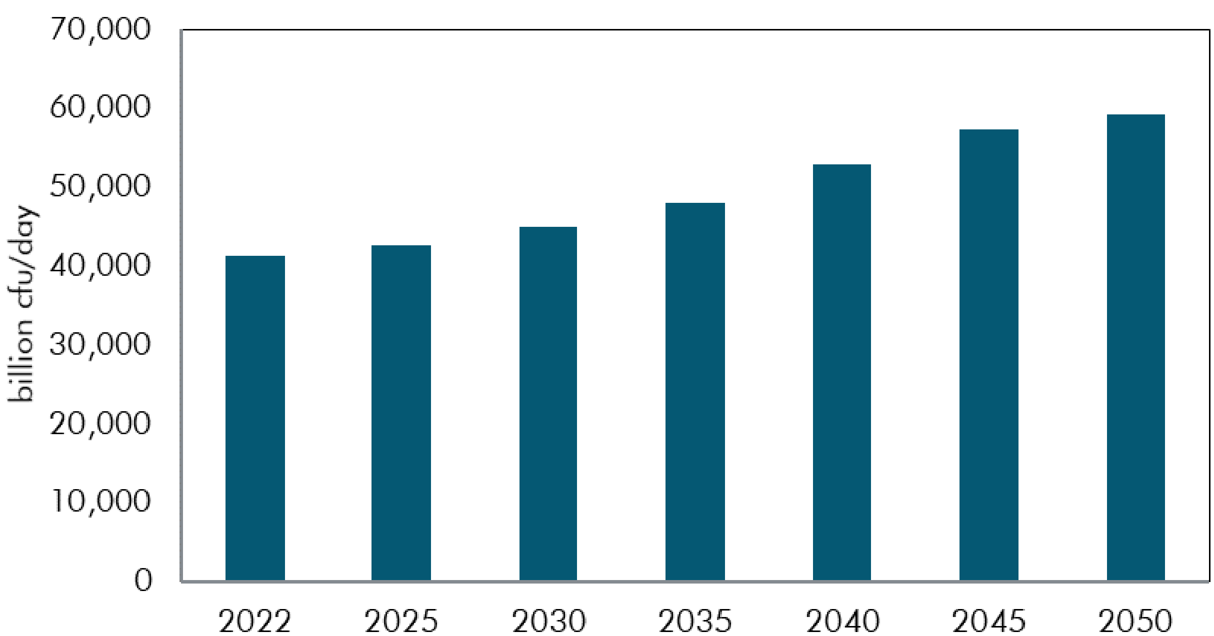

Figure 24. Total Potential Daily Loads, 2022-2050

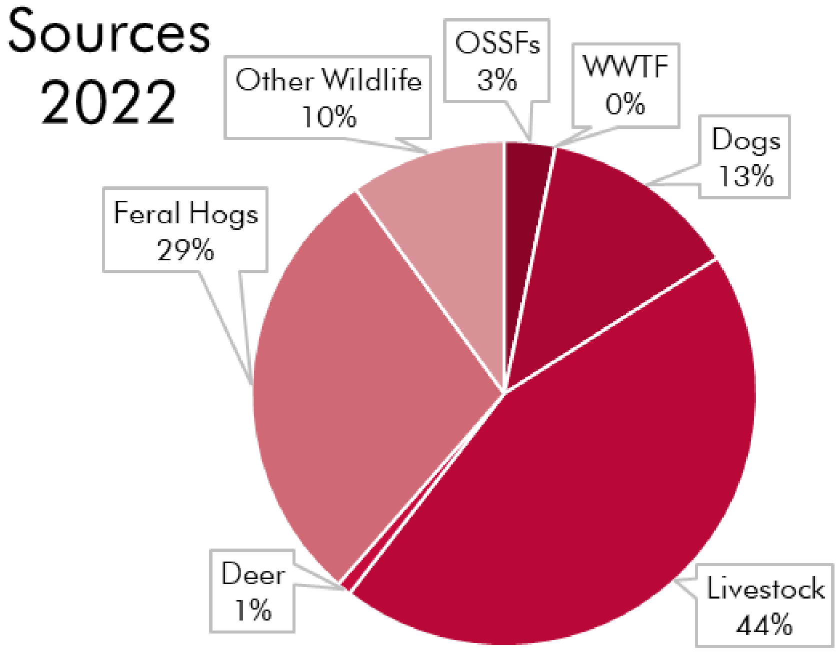

Figure 25. Fecal Indicator Bacteria Source Profile, 2022

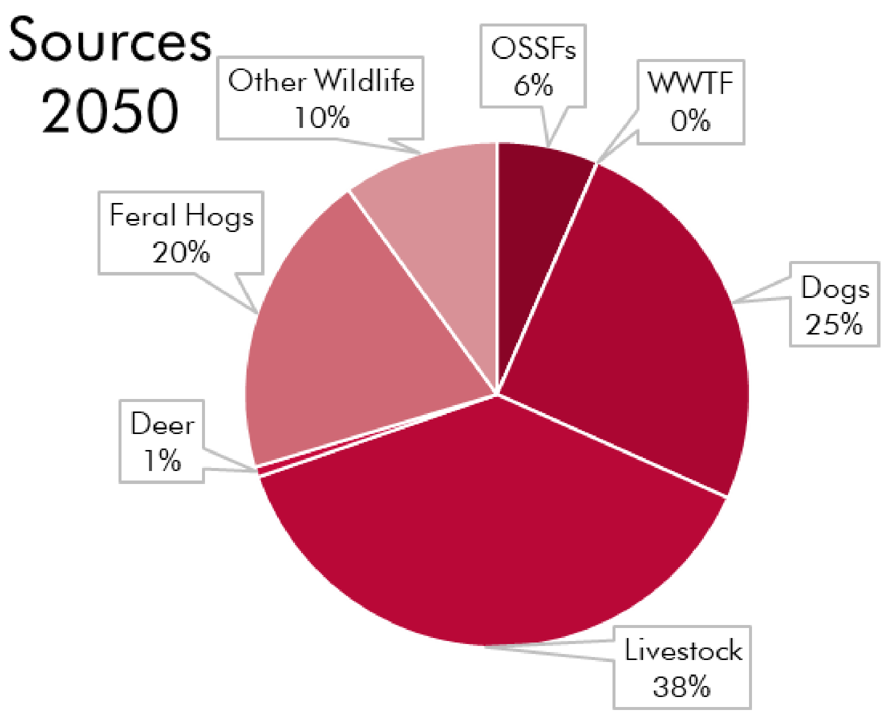

Figure 26. Fecal Indicator Bacteria Source Profile, 2050

SECTION 6: OUTCOMES AND IMPLICATIONS

6.1 Overview of Outcomes

The results of LDC and SELECT models generated for this report indicate different fecal bacteria reduction needs for different areas of the watershed dictated by a complex mix of sources which are predicted to shift in coming years. Among these sources, livestock waste was determined to be the dominant pollutant in both current and projected scenarios. The methodologies implemented in the design of these model results may be refined by stakeholder feedback as the partnership progresses through the stages of WPP development. From these data, fecal bacteria reduction targets and implementation timelines may be established by linking the results of LDC and SELECT models.

6.2 Model Linkage

LDC analyses helped to determine fecal bacteria reduction targets at different rates of streamflow for different sites throughout the watershed area. These models also helped identify similar spatial trends that will aid in the selection of target areas for implementing specific fecal bacteria reduction strategies. SELECT models helped to spatially visualize potential fecal bacteria loads contributed by known sources and characterize the proportion of those loads to each other and to the overall total. This is important for determining how to approach fecal bacteria reduction throughout the watershed most effectively. The methods used to generate both LDC and SELECT models were developed with H-GAC and TCEQ project staff for quality assurance. Fate and transport relationships of fecal bacteria loads were not captured in these analyses. However, modifications were made to the base SELECT model to infer generalized linear relationships between source loading instream and in the watershed area at large. Most importantly, a buffer zone was established around the stream network which led to the distinction between sources directly impacting waterways and those with more indirect effects delivered via runoff and other high flow events. The level of precision achieved with more complex models does not produce an appreciably more useful level of information for stakeholders determining best management practices for their watershed. Other WPPs in the region have used similarly modified SELECT models with success as an efficient, accessible method of answering the needs of a project of this scale. Though a certain level of uncertainty is acknowledged in this approach, the general outcomes of these assessment will be defensible and suitable for guiding implementation.

6.3 Fecal Indicator Bacteria Reduction Targets

Three main points help to guide the decision-making process for determining fecal bacteria reduction targets. First, a checkpoint must be determined for gaging the progress of actions taken to improve water quality in the watershed. This checkpoint is referred to as a milestone year. Secondly, managers must decide the scope of reduction targets and whether they will apply to specific target areas or if they will be more effective on a larger scale. Finally, reduction targets should be allocated proportional to the known sources contributing to fecal bacteria loading in the watershed.

Milestone Year

Typically, WPPs are written to provide a guideline for making improvements to water quality within a period of five to 15 years. By incorporating five-year intervals into future projections of fecal bacteria loading with the SELECT models used in this report, stakeholders will be able to target any year on the timeline between the present day and 2050 as a milestone year. While intervals closer to the present-day present challenges for organizing and implementing water quality improvement strategies, estimates for fecal bacteria loading further along the timeline are subject to higher levels of uncertainty. Therefore, a balance must be reached between selecting a milestone year that effectively addresses fecal bacteria loading for a long-term outlook while working within an acceptable margin of error regarding uncertainty. As a compromise, project staff recommend targeting the year 2040 as a milestone for this watershed project. With a WPP approval planned between 2024 and 2025, this would cover a period of about 15 years.

Target Areas

In both LDC and SELECT model results, different fecal bacteria source pressures are indicated in different areas of the watershed. To streamline the process of determining load reduction targets while recognizing different loading pressures affecting different areas of the watershed, project staff recommend using attainment areas as the base level target areas for determining fecal bacteria reductions. Attainment areas are groupings of similar geographical areas such as subwatersheds which share similar characteristics including land cover or pollutant loading pressures. The East Fork San Jacinto subwatersheds were grouped into three attainment areas (Table 18). The respective stream segments and watershed areas for station 21417 and 21934, along with those of Nebletts Creek, were grouped together into an attainment area because of the similarities in model results and land cover and to differentiate the tributary portion of the watershed from the subwatersheds representing the East Fork of the San Jacinto River. The "East Fork San Jacinto River Tributaries" attainment area will be represented by Station 21417 due to its location (furthest downstream) and data record. The Lower East Fork San Jacinto River subwatershed is unique due to the large percentage of developed land cover in this area. This subwatershed will comprise a separate attainment area represented by data from Station 11235. The remaining subwatersheds (Middle and Upper East Fork San Jacinto River) will be grouped into a final attainment area due to similarities in LDC model results and land cover. The representative station for this "Upper East Fork San Jacinto River" attainment area will be Station 11238. After further review with stakeholders, additional targets may be added if more specific water quality goals are needed.

By designating these three generalized attainment areas (**Figure 27**), overall reduction targets compromising between over-generalization of the total watershed and overly conservative reduction targets for individual subwatersheds at different rates of flow can be applied in the development of a WPP. Overall reduction targets for each attainment area were determined using the representative station for the area and taking a weighted average of the LDC reduction targets produced for that station based on rates of flow. Therefore, where W represents the weighting factor (percent of flows) at high flow (*h*), moist (*m*), mid-range (*mr*), dry (*d*), and low flow (*l*) conditions, and R represents the reduction value required at each rate of flow, the weighted average reduction can be calculated as follows:

$$\text{Weighted Average Reduction} = \frac{\text{W}h\text{R}h + \text{W}m\text{R}m + \text{W}mr\text{R}mr + \text{W}d\text{R}d + \text{W}l\text{R}l}{\text{W}h + \text{W}m + \text{W}mr + \text{W}d + \text{W}l}$$

For example, Station 11235 is the farthest downstream station in the attainment area of the lower East Fork San Jacinto River and was used to represent the area**Error! Reference source not found.**. At the high flow category which represents the top 10% of flows, an *E. coli* reduction of 83% is recommended. *E. coli* observed in the next 30% of flows (moist conditions) require a reduction of 56% and *E. coli* observed in the following 20% of flows (mid-range conditions) require a 31% reduction. Finally, *E. coli* observed in dry conditions comprising the following 30% of flows only require a 1% reduction. Low flow conditions are not factored into this calculation as no reductions were indicated by the LDC model. The calculation for the weighted average reduction for Station 11235 is shown below:

$$\text{Weighted Average Reduction} = \frac{(10 \times 83) + (30 \times 56) + (20 \times 31) + (30 \times 1)}{10 + 30 + 20 + 30}$$

$$\text{Weighted Average Reduction} = \frac{830 + 1{,}680 + 620 + 30}{90}$$

$$\text{Weighted Average Reduction} = \frac{3{,}160}{90} = 35.1$$

This calculation was also used to determine the weighted average fecal bacteria percent reduction needed at Station 11238 which was selected as the best representative station in the upper East Fork San Jacinto attainment area, and Station 21417 which represents the attainment area for the tributaries of the East Fork San Jacinto River**Error! Reference source not found.**. Only weighting factors and reduction targets from high, moist, and mid-range flows were considered for Station 11238 as no reductions were indicated by the LDC model at dry and low flow conditions. For the same reason, only high and moist conditions were used in the weighted average reduction target calculation for station 21417.

Table 18. Attainment Areas and Fecal Indicator Bacteria Load Reduction Goals

Attainment Area	LDC Station	Subwatersheds	Weighted Average *E. coli* Reduction Target
Lower East Fork San Jacinto River	11235	1	35%
Upper East Fork San Jacinto River	11238	2 and 3	38%
East Fork San Jacinto River Tributaries	21417	4, 5, and 6	36%

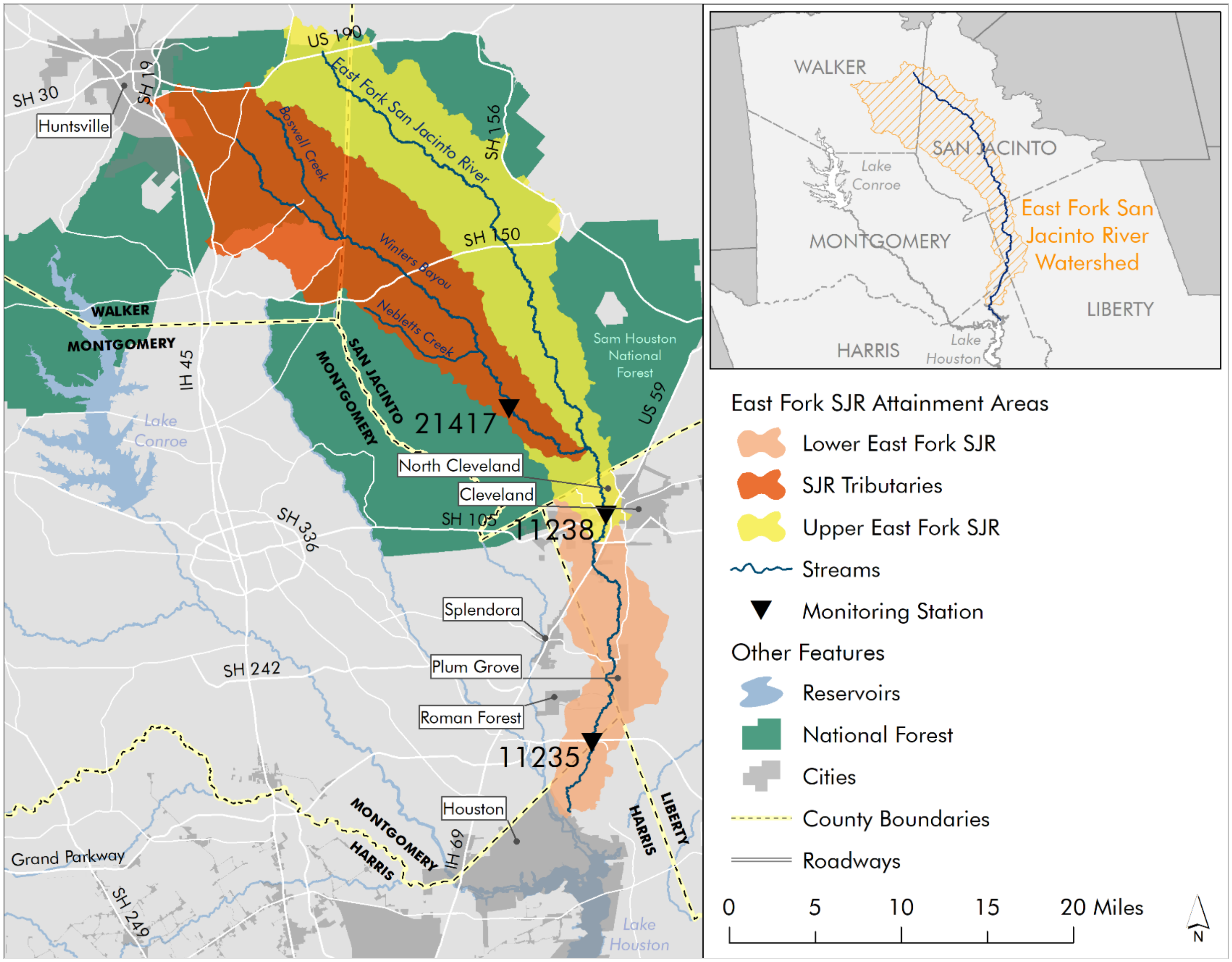

Figure 27. Fecal Indicator Bacteria Attainment Areas

Allocating Reductions

Many methods can be implemented to determine the most appropriate course for allocating reductions to different fecal bacteria loading sources in a watershed area. Among them are:

1) Allocating reduction targets relative to source contributions estimated for the milestone year
2) Allocating reduction targets subjectively based on implementation strategies deemed most feasible and effective by area stakeholders
3) Allocating reduction targets relative to source contributions estimated for current conditions

For the needs of this watershed, project staff recommend the first option as it allows stakeholders some flexibility in focusing short-term efforts on sources indicated as greater pressures in current conditions relative to the milestone year. While proportional allocations are modeled at the subwatershed level, the attainment area level, and for the total watershed area, project staff further propose targeting results from the attainment areas. According to these recommendations, both overall reduction targets for each of the attainment areas and the linkage of the reduction target percentages to the source loadings to generate the target source load reductions for current and 2040 milestone years were calculated (**Table 19**). The allocation of reduction loads by source for each of the three attainment areas were also calculated (**Table 20**; **Table 21**; **Table 22**).

Table 19. 2022 and 2040 Source Load Reduction Targets

Attainment Area	Subwatersheds	Weighted Average *E. coli* Reduction Target	2022 Total Source Load in Billion cfu/day[15]	2022 Source Load Reduction Target in Billion cfu/day	Incremental Load, 2022 to 2040 in Billion cfu/day[16]	2040 Total Source Load Reduction Target in Billion cfu/day[17]
Lower East Fork San Jacinto River	1	35%	7,821.74	2,737.61	7,737.36	10,474.97
Upper East Fork San Jacinto River	2 and 3	38%	15,293.54	5,811.55	1,029.77	6,841.31
East Fork San Jacinto River Tributaries	4, 5, and 6	36%	18,206.81	6,554.45	2,774.56	9,329.01

[15] Current source load is generated by summing the source loads for the subwatersheds within the attainment area.
[16] The incremental load represents the difference between the 2040 load and the 2022 load. See the next footnote for explanation of its use in generating 2040 source reduction load target.
[17] The 2040 reduction target is generated by through the equation $C_r+(F_l-C_l)$; where C_r= current source reduction load, F_l = future total source load, and C_l = current total source load. In essence, the incremental load generated between 2022 and 2040 is added to whatever existing reduction load exists in 2022. This approach is used because LDCs cannot estimate future reduction percentages, and because it is assumed the waterway will not have additional assimilative capacity in 2040.

Table 20. Load Reduction Targets by Source, Lower East Fork San Jacinto River Attainment Area

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	15%	1,523.67
WWTFs	0%	2.64
Dogs	57%	5,976.13
Cattle	6%	637.57
Horses	0%	15.84
Sheep and Goats	2%	243.30
Deer	0%	31.58
Other Wildlife	10%	1,047.50
Feral Hogs	10%	996.75
Total	**100%**	**10,474.97**

Table 21. Load Reduction Targets by Source, Upper East Fork San Jacinto River Attainment Area

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	3%	235.43
WWTFs	0%	1.78
Dogs	17%	1,191.27
Cattle	27%	1,873.27
Horses	0%	13.66
Sheep and Goats	10%	714.85
Deer	1%	66.05
Other Wildlife	10%	684.13
Feral Hogs	30%	2,060.87
Total	**100%**	**6,841.31**

Table 22. Load Reduction Targets by Source, East Fork San Jacinto River Tributaries Attainment Area

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	1%	85.29
WWTFs	0%	0.49
Dogs	3%	275.86
Cattle	45%	4,235.98
Horses	0%	30.89
Sheep and Goats	17%	1,616.48
Deer	1%	67.50
Other Wildlife	10%	932.90
Feral Hogs	22%	2,083.62
Total	**100%**	**9,329.01**

6.4 Implications of Findings

Models characterizing fecal bacteria loads and sources in the East Fork San Jacinto River watershed reinforce the concept of a watershed beset by a diverse range of pressures impacting water quality. Future projections indicate that the expansion of developed areas may affect the balance of pressures impacting the overall bacteria load.

Action must be taken to reduce fecal bacteria loading and improve overall water quality in the East Fork of the San Jacinto River and its tributaries to ensure the waterways are safe for recreation, aquatic life, and myriad other uses. Without executing appropriate management strategies, current water quality issues will be compounded by future loads, leading to degrading water quality in the coming years.

Models generated for this report are intended to provide the best available information to stakeholders hoping to take such action in the watershed. As with all models, a certain level of uncertainty is acknowledged. However, by combining quality assured methods with stakeholder feedback, project staff will work to minimize uncertainty wherever possible. Further refinement of results may be needed in the future considering changing conditions. By assessing current and predicted trends in water quality presented in this report and understanding the impacts of sources influencing fecal bacteria loads, stakeholders can form effective plans specific to their watershed that can help to make positive changes in water quality that will benefit their communities today and in the future.